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NOISE AND VIBRATION IN MINES
RESEARCH REPORTS 1972-1986

edited by G. Knight ***traduit par N.R Billette***

Volume 6 MRL 88–121 (R)

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CANMET

Canada Centre for Mineral and Energy Technology

Centre canadien de la technologie des minéraux et de l'énergie

NOISE AND VIBRATION IN MINES RESEARCH REPORTS: 1972-1986. VOLUME 6—VIBRATION STUDIES and GENERAL

BRUIT ET VIBRATION DANS MINES RAPPORTS DE RECHERCHE ÉTUDES DES VIBRATIONS ET DIVERS

Edited by G. KNIGHT

Canadian Mine Technology Laboratory

Traduit par N.R. Billette

Laboratoire canadien de technologie minière

MARCH 1988

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LABORATOIRES DE RECHERCHE MINIÈRE

RAPPORT DE DIVISION LRM 88–121 (R)

FOREWORD

The compendium of CANMET reports on noise measurement equipment, noise assessments in mines and hearing protection assessments is a tribute to the dedication, hard work and professional expertise of Mr Savich in his field of research specialization. The research contained within the reports was accomplished by Mr. Savich or under his direction in the relatively brief period of 1972 to 1986 while working as a research scientist at the Elliot Lake Laboratory.

It is hoped that this compendium of reports on research carried out while at CANMET will be useful to those interested in finding solutions to the problems caused by miner exposure to noise and vibration.

J.E. Udd
Director
Mining Research Laboratories

AVANT-PROPOS

Le recueil de rapports de CANMET sur les instruments de mesure du bruit, les évaluations du bruit dans les mines et la protection de l'ouïe constitue un hommage à l'assiduité, le professionnalisme et l'expertise de M. Savich dans son champ de spécialisation en recherche. La recherche relatée dans ces divers rapports fut accomplie par M. Savich lui-même, ou sous sa direction, au cours de la courte période allant de 1972 à 1986, alors qu'il oeuvrait en tant que chercheur scientifique au laboratoire d'Elliot Lake.

Les Laboratoires de recherche minière de CANMET espèrent que ce recueil de rapports de recherche serviront à tous les intervenants du milieu intéressés aux problèmes reliés à l'exposition des mineurs au bruit et aux vibrations.

Directeur
Laboratoires de recherche minière
J.E. Udd

NOISE AND VIBRATION IN MINES — RESEARCH REPORTS: CANMET/ MINING RESEARCH LABORATORIES, 1972-1986.

Reprinted in 6 Volumes

Edited by

G. Knight*

French translations by

N.R. Billette*

ABSTRACT

This compendium is a reprint of all the reports on noise and vibration research undertaken by CANMET. Most of the studies were undertaken in cooperation with mines across Canada, mainly mines located in Ontario and on several occasions with the Mines Accident Prevention Association of Ontario. Two studies were carried out through the awarding of contracts.

The compendium is in 6 volumes, two of which are in parts, as follows;

1. Vol. 1–Glossary, Introduction, and Measurement Methods.
2. Vol. 2–Hearing Protection—Ear Muffs.
3. Vol. 3–Mine Noise Surveys–Part A.
4. Vol. 3–Mine Noise Surveys–Part B.
5. Vol. 3–Mine Noise Surveys–Part C.
6. Vol. 4–Mill and Surface Plant Noise Surveys–Part A.
7. Vol. 4–Mill and Surface Plant Noise Surveys–Part B.
8. Vol. 5–Noise Abatement Studies.
9. Vol. 6–Vibration Studies and General(includes unclassified)

Within each volume or section the reports are listed chronologically. The glossary has been removed from 3 of the reports and listed separately at the front. The introduction describes the main features of the contained studies in each volume.

KEYWORDS: Noise, vibration, mine surveys, noise control,
hearing protection, bibliography.

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BRUIT ET VIBRATION DANS LES MINES - RAPPORTS DE RECHERCHE: LABORATOIRES DE RECHERCHE MINIÈRE DU CANMET, 1972-1986.

Réimpression (en anglais) dans 6 Volumes

édité par — traduit par
G. Knight* — N.R. Billette*

RÉSUMÉ

Ce recueil constitue une réimpression de tous les rapports concernant la recherche sur le bruit et les vibrations exécutée à CANMET. La plupart des travaux ont été entrepris en collaboration avec des mines canadiennes, principalement avec des mines situées en Ontario et, en de nombreuses occasions, avec l'assistance de l'Association de prévention des accidents miniers en Ontario (MAPAO). Deux recherches furent réalisées en tant que contrats.

Le recueil comprend 6 volumes, dont deux comprenant plus d'une partie, répartis comme ceci:

1. Vol. 1–Glossaire, introduction et techniques de mesure.
2. Vol. 2–Protection de l'ouïe - protecteurs supra-auriculaires.
3. Vol. 3–Relevés de bruits de mines–partie A.
4. Vol. 3–Relevés de bruits de mines–partie B.
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8. Vol. 5–Études de réduction du bruit.
9. Vol. 6–Études des vibrations et divers.

Dans chaque volume ou section, les rapports sont classés en ordre chronologique. Le glossaire (en anglais seulement) provient de l'amalgamation de termes contenus dans trois des rapports et a été regroupé séparément au début. L'introduction décrit les principaux éléments des travaux contenus dans chaque volume.

MOTS-CLÉS: bruit, vibration, relevé en mine, contrôle du bruit, protection auriculaire, bibliographie.

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INTRODUCTION

This research was undertaken because noise-induced hearing loss is a substantial problem in the mining industry and because vibration-induced damage occurs to blood capillaries in the hands of miners, particularly drillers. Noise-induced hearing loss generally occurs over a long period of time. Because humans are adaptable and tend to compensate for the gradual loss, the impairment goes unrecognized for a long time. Exposure to very loud noises, such as explosions, can give rise to immediate and disabling damage to the hearing system.

Hearing impairment affects both employees and employers. Compensation payments are becoming substantial. The hearing loss can only be detected in the early stages by frequent checks of hearing acuity and this is now required for miners in most Canadian jurisdictions.

Noise is measured as the peak to trough pressure difference in the vibration waves in air. The results are expressed in relative terms to the hearing sensitivity of (young adult) humans in good health using a logarithmic scale to the base 10. Thus, an increase of one Bel is equivalent to a ten times stronger noise level. However, the Bel is a large unit and it is more convenient to use a unit ten times smaller, the decibel. Hearing acuity is frequency dependent. It peaks at a frequency of about 1 000 Hertz (cycles per second) and falls off to the extreme limits, roughly 20 and 20 000 Hz. Sound measurement equipment is much less frequency dependent and a weighting factor is used to relate it to human hearing. The "A"-scale is used in hearing loss programs generally. Thus, the weighted noise level in decibels is usually abbreviated as dBA. Hearing loss is believed to occur when exposure is above a threshold level, 85 dBA and 90 dBA have been specified in various jurisdictions. The hearing loss is proportional to the height of the noise excursion and its duration. Three factors are in use for equating the potential hearing loss to the noise level:

1. A doubling every 3 dBA–The equal energy principle, used in many hearing loss control recommendations.
2. A doubling every 4 dBA–used in one or more recommendations.
3. A doubling every 5 dBA–used in the principal USA legislation: the Occupational Safety and Health Act (OSHA).

Canadian regulations are set provincially and federally: either factor 1 or 3 is used.

In addition to potential hearing losses high noise levels lead to problems in safety, fatigue and communication.

Most of the noise studies have been directed at surveys of noise in mines and the efficacy of hearing protection measures. The mine surveys have shown that many miners are exposed to noise levels above the threshhold for potential hearing loss and that immediate hearing protection is required as well as an effort to reduce the noise level of mining machinery.

This compendium is a reprint of all the reports on noise and vibration research undertaken by CANMET. Most of the studies were undertaken in cooperation with mines across Canada, mainly mines located in Ontario and, on several occasions, with the Mines Accident Prevention Association of Ontario. Two studies were carried out through the awarding of contracts. A few of the early reports by Miron Savich were based on his MSc. thesis work undertaken at the Institute of Mineral Research of McGill University, situated at Mont St. Hilaire, Quebec.

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9. Vol. 6–Vibration Studies and General(includes unclassified)

Within each volume or section the reports are listed chronologically. The glossary has been removed from 3 of the reports and amalgamated. It is presented separately at the front, following the contents table.

The noise measurement methods used are described in some reports in the first volume as well as being described in many of the other reports on surveys etc.. Five main classes of noise measurement techniques have been used in the noise surveys. These are:

1. Hand-held meters with "A"-scale weighting and slow response time averaging over a short period of time, a second or less, with manual recording. This was used in the earlier surveys and occasionally later. A graphical method of determining the average noise level for the survey is given in report 75–71.
2. The hand-held sound level meter was also used in the peak measurement mode for studies of impulse, or short duration, noise as in report 84–83.

3. A shift length recording system in which the average noise level over a period, such as a minute, is stored on a memory bank and read out later. In the system used, the results were read at the end of the shift and analysed using a computer program as described in report 78–62.

4. The noise dosimeter averages noise level over a short period of time and, if it exceeds the threshhold, adds it up using an appropriate factor to give the noise level as a ratio of the exceedance to permissible for the shift. The instrument usually has an indicator for showing whether the noise level has exceeded the ceiling level of 115dBA promulgated in the OSHA regulations (presumably intended for unprotected ears). This instrument has been used in many surveys and tests on hearing protectors. One unit was described and tested in report 76–83.

5. Frequency analysis sound level meter. This determines the sound level in each band of frequency of significance, usually one third octave wide. The equipment is desirable because the attenuation of noise by any barrier is frequency dependent and because the frequency of an offensive sound may be very helpful in determining its source. Ear muffs are sound attenuators and therefore frequency dependent, they are not as good attenuators at low frequencies as at high frequencies.

Ear muffs (hearing protectors) were shown to be highly efficient in laboratory tests providing attenuations of 31 to 44 dBA at frequencies of 1 000 Hz and above. Safety glass-frames passing under the seal of the ear muff, however, were found to reduce attenuations to 25 to 34 dBA. The wearing of safety glasses is obligatory in most working places in the mining industry. Field studies in mines showed that the effective protection factors for ear muffs could be less than 10 dBA. The surveys carried out at Falconbridge Mines Ltd., Reports 86–58, 86–59, 86–60, 86–61 with a final summary in 86–88 illustrate the value of such studies. The attenuations of ear muffs found in mines are shown in Figure 1, where the measured attenuation(OSHA basis) in dBA is shown plotted against the mean sound level in dBA (variously described in the reports as $L_{eq}(60s)$; L_{OSHA} or $L_{Avg.}$). The required attenuation line is drawn assuming that the average sound levels persist for a full 8 hour shift and that ear plugs are not worn. This figure suggests that about half of the population examined were not protected to the extent required. However, neither of these assumptions are true and it is probable that substantially more than the half of the population was protected to the extent required. The major reason for the poor performance of ear muffs in practise was found to be poor fitting, the spring clamping force was often inadequate, particularly on small headed individuals. Emphasis was placed on the measurement and control of clamping force and the need to fit earmuff supports to head size. On the basis of these surveys recommendations were made to improve control of hearing protection programs.

The noise surveys are a useful repository of information. The detailed surveys, using the data logging technique, which form the major part of volumes 3 and 4, provide invaluable information to those planning noise control programs in many mining operations. Nearly 700 man-days were logged in the detailed surveys. It could be seen that the distribution of noise exposure during the shift varies from nearly constant to highly variable. In the mines 262 shifts out of the 432 recorded were worked at sound levels above permissible exposure. The highest values were about 40 times greater requiring hearing protection of at least 28 dBA attenuation. This would be even higher if the proposed OSHA standards instead of the existing rules (at the time the reports were written) were used as the basis for assessment. In the mills and surface plants only 13 out of the 250 shifts recorded were worked at sound levels above permissible exposure. The highest value required about 10 dBA attenuation in the hearing protection.

Noise control studies have been carried out with respect to light and medium weight percussion rockdrills, diamond drills and diesel engine exhaust systems. The diamond drill studies point out the need for a thorough investigation of all the noise sources, four major sources have been identified. Reduction of only one source would, as a result, produce almost no effect on sound level, a reduction of about 1 dBA. It may, however, modify the sound quality significantly.

The high noise levels measured in mining emphasize the requirement for substantial work to control noise on mining machinery. It is likely that eventually it will be desirable not to expose men to sound levels over 85 dBA and that the necessity for hearing protection will be considered an undesirable working condition to be eliminated.

The contract study on vibration found that stopers and jackleg drills subjected miner's hands to vibration levels sufficient to induce vibration white finger disease in periods of one to four years in over half the population. It was also shown that vibration isolators could be effective in substantially reducing vibration transmission to hands and proposed that vibration isolation handles should be developed and used on percussion drills. Some sites where whole-body exposure to vibration exceeded guidelines were found in surface plant and mills. Underground diesel powered vehicles were not examined.

The report 73–17 in the miscellaneous section in volume 6 is a good exposition of the noise and vibration problems in mines. The topics covered include noise and vibration measurement; noise and vibration exposure standards; and noise and vibration sources; as well as control methods.

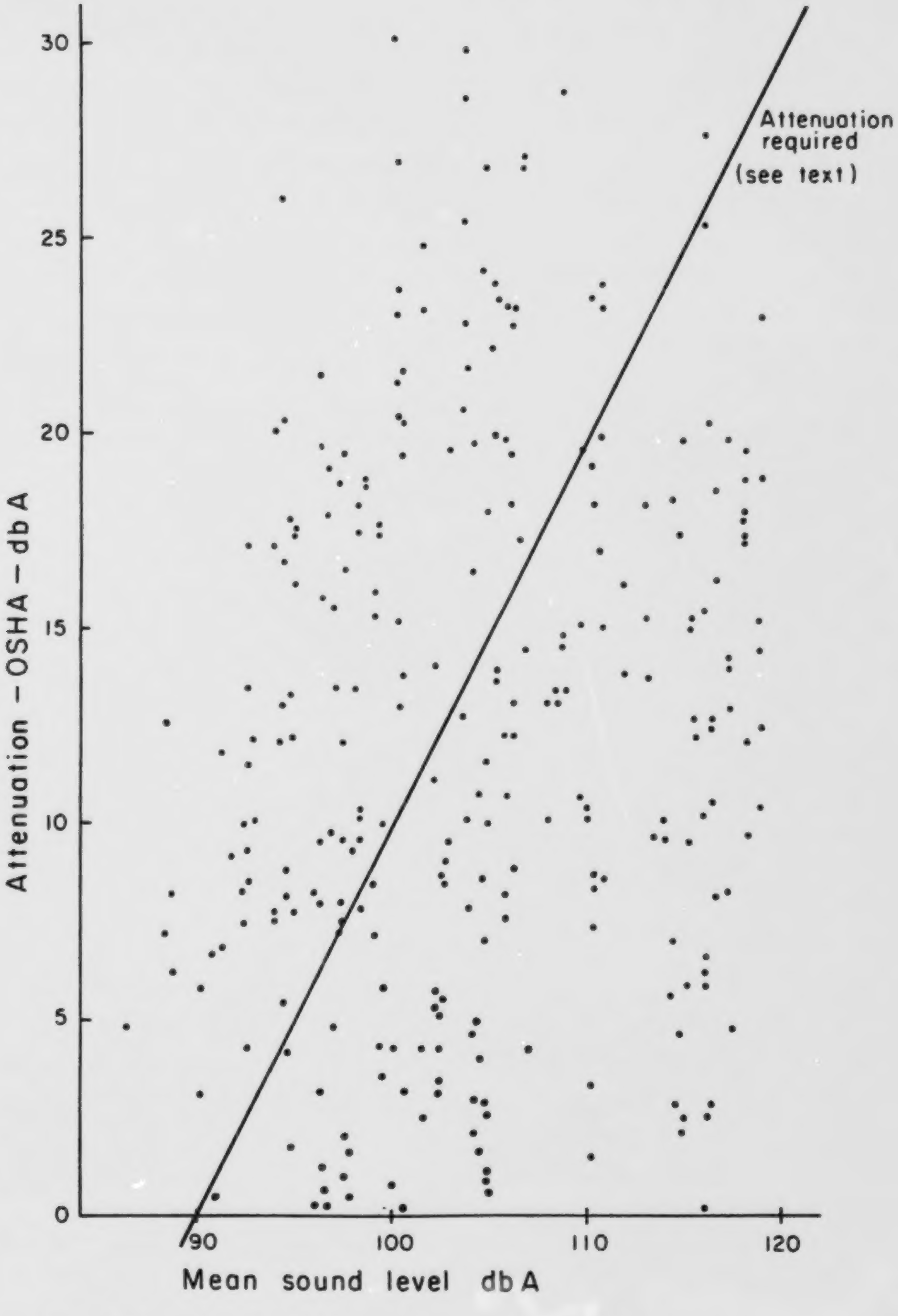

Fig. 1–The attenuation of ear muffs measured in use in mines.

Fig. 1–L'atténuation des protecteurs supra-auriculaires en usage dans le mines

It should be appreciated that many of the reports cover more than one topic and that they have not been cross-referenced. They are entered in the category corresponding to the major aspect studied.

The report pages have not been renumbered. To assist in locating each report red coloured pages are used to separate them. Each of these has page and report numbers in the top right hand corner and the full title and description of the report and its publication details, if other than a divisional report.

The reports are in their original language, usually english. The abstracts have been translated into french and are given at the front of each report.

ACKNOWLEDGEMENTS

The editor wishes to thank his colleagues in the Mining Research Laboratories for assistance in gathering and compiling these reports.

INTRODUCTION

Ces travaux de recherche ont été entrepris parce que la perte auditive due au bruit constitue un problème important dans l'industrie minière, ainsi qu'à cause des dommages aux capillaires sanguins induits par vibration aux mains des mineurs, et plus particulièrement des foreurs. La perte auditive due au bruit découle d'une exposition prolongée. Puisque les humains s'adaptent facilement et tendent à compenser la perte graduelle, la détérioration passe longtemps inaperçue. Toutefois, l'exposition à de très grands bruits, une explosion par exemple, peut entraîner un dommage immédiat incapacitant du système auditif.

La perte auditive affecte tant l'employeur que l'employé. Les paiements compensateurs sont devenus substantiels. Les premiers signes de dégradation de l'ouïe ne sont reconnus qu'au prix de multiples vérifications de l'acuité auditive, ce qui est maintenant exigé dans la plupart des juridictions canadiennes concernant les mineurs.

Le bruit est mesuré comme différence entre le sommet et le creux des ondes vibratoires dans l'air. Les résultats sont exprimés en termes relatifs à la sensitivité auditive d'un humain (jeune adulte) en bonne santé, en utilisant une échelle logarithme de base 10. Ainsi, une augmentation du niveau sonore d'un Bel équivaut à décupler l'énergie acoustique. Toutefois, le Bel constitue une unité représentant une somme énergétique importante, de sorte qu'il est plus approprié d'utiliser le décibel, une unité dix fois plus petite. L'acuité auditive dépend de la fréquence de l'onde. Elle atteint son maximum aux alentours de la fréquence de 1,000 Hertz (cycles par seconde) et diminue aux deux extrémités du spectre, soit 20 et 20,000 Hz respectivement. L'équipement de mesure du son est beaucoup moins dépendant de la fréquence utilisée, de sorte qu'un facteur de pondération est nécessaire pour relier le niveau sonore à l'acuité auditive humaine. L'échelle "A" est généralement utilisée dans les programmes de perte auditive. Dans ce cas, le niveau sonore pondéré est habituellement abrégé à dBA. La perte auditive est considérée se produire au-delà d'un seuil, 85 dBA et 90 dBA étant la norme dans diverses réglementations. La perte auditive est proportionnelle à la puissance de l'onde sonore et à la durée de l'exposition. Trois facteurs légaux sont utilisés pour établir la relation entre dommage potentiel et niveau sonore:

1. Le dommage double tous les 3 dBA – le principe d'énergie équivalente, à la base de nombreuses recommendations du contrôle de la perte auditive.
2. Le dommage double tous les 4 dBA – utilisé dans une recommendation ou plus.
3. Le dommage double tous les 5 dBA – en usage dans la principàles législation américaine, l'Acte de santé et sécurité occupationnelles (OSHA).

Les réglementations canadiennes sont émises aux niveaux provinciaux et fédéral: elles utilisent le facteur 1 ou le facteur 3.

En plus des pertes auditives potentielles, les niveaux sonores élevés entraînent des problèmes de sécurité, de fatigue et de communications.

La plupart des travaux sur le bruit ont été orientés vers des relevés du bruit dans les mines et vers l'appréciation de l'efficacité des mesures de protection de l'ouïe. Les relevés dans les mines ont démontré que plusieurs mineurs sont exposés à des niveaux sonores supérieurs au seuil de dommage auditif potentiel et qu'une protection immédiate de l'ouïe est nécessaire en parallèle à l'implantation de mesures de réduction du bruit de l'équipement et matériel minier.

Ce recueil incorpore tous les rapports de recherche sur le bruit et les vibrations réalisés par CANMET. La plupart des travaux ont été réalisés en collaboration avec des mines canadiennes, principalement avec des mines situées en Ontario et, à maintes reprises, avec l'assistance de l'Association de prévention des accidents miniers en Ontario (MAPAO). Deux recherches furent réalisées sur une base contractuelle. Quelques uns des premiers rapports de Miron Savich étaient basés sur sa thèse de maîtrise réalisée à l'Institut de Recherche minérale de l'Université McGill, situé à St-Hilaire, Québec.

Le recueil comprend six volumes, dont deux en plusieurs parties, comme suit:

1. Vol. 1–Glossaire, introduction et techniques de mesure.
2. Vol. 2–Protection de l'ouïe - protecteurs supra-auriculaires.
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4. Vol. 3–Relevés de bruits de mines–partie B.
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6. Vol. 4–Relevés de bruits d'usines et ateliers de surface–partie A.
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Dans chaque volume ou section, les rapports sont classés en ordre chronologique. Le glossaire (en anglais seulement) provient de l'amalgamation de termes contenus dans trois des rapports. Il est présentement à part au début, tout de suite après la table des matières.

Les techniques de mesure du bruit utilisées sont décrites dans quelques rapports du premier volume, ainsi que dans de nombreux autres reliés aux relevés de mines, usines et ateliers. Cinq classes principales de techniques de mesure du bruit ont été expériementées dans les relevés sonores. Ce sont:

1. Des appareils manuels pondérant les fréquences selon l'échelle "A", avec un temps de réponse assez lent et le calcul de la valeur moyenne sur une brève période, une seconde ou moins, et enregistrement manuel du résultat. Il s'agit de la technique utilisée lors des premiers relevés, puis occasionnellement par la suite. Une méthode graphique pour déterminer le niveau acoustique pondéré au cours du relevé est expliquée dans le rapporté 75-71.
2. Le sonomètre manuel a aussi été utilisé en mode de mesure des bruits d'impact pour des études d'impulsion, ou bruit de courte durée, comme dans le rapport 84-83.
3. Un système d'enregistrement pour la période de travail (8 heures), qui cumule le bruit moyen d'une période de courte durée, une minute par exemple, et la conserve en mémoire pour lecture ultérieure. Le système utilisé permettait la lecture de l'information à la fin de la période de travail et son traitement ultérieur informatisé, tel que décrit dans le rapport 78-62.
4. L'audio-dosimètre calcule le niveau sonore moyen sur une courte période de temps et, surtout s'il excède le niveau légal, calcule le rapport du niveau sonore obtenu au niveau permis pour la période de travail. L'instrument possède également un voyant lumineux qui indique un dépassement de la limite légale absolue de 115 dBA promulguée dans les règlements OSHA (sans aucun doute pour une ouïe sans protecteur). Cet instrument a été utilisé dans plusieurs relevés et lors de tests concernant les protecteurs auriculaires. Un tel appareil a été décrit et vérifié dans le rapport 76-83.
5. Le sonomètre d'analyse fréquentielle. Cet instrument mesure le niveau acoustique moyen dans chaque bande de fréquence significative, habituellement de la largeur d'un tiers d'octave. L'instrument est nettement recommandable, puisque l'atténuation du bruit par toute barrière est fonction de la fréquence et parce que la fréquence d'un son agresseur contribue à localiser sa source. Les protecteurs auriculaires sont des atténuateurs de son et, de ce fait, dépendent de la fréquence d'émission. Ils n'atténuent pas les basses fréquences avec autant de bonheur que les hautes fréquences.

Les protecteurs supra-auriculaires ont démontré des habiletés d'atténuation allant de 31 à 44 dBA en laboratoire pour les fréquences de 1,000 Hz et plus. Les montures de lunettes de sécurité passées sous les coussins du protecteur réduisent cependant la protection qui passe alors de 25 à 34 dBA. Comme le port de lunettes protectrices est obligatoire pour la plupart des postes de travail dans l'industrie minière, des études sur le terrain dans les mines ont démontré que la protection réelle obtenue par des protecteurs supra-auriculaires peut ne pas dépasser 10 dBA. Les relevés effectués à Falconbridge Ltée, rapports 86-58, 86-59, 86-60, 86-61 avec un résumé final dans 86-88, illustrent la validité de tels travaux. La figure 1 (voir page 5) illustre l'atténuation en dBA (base OSHA) des protecteurs supra-auriculaires en usage dans les mines, où cette dernière est comparée au niveau acoustique pondéré en dBA (décrit différemment dans les rapports comme $L_{eq}(60s)$; L_{OSHA} ou $L_{Avg.}$). La ligne d'atténuation requise est illustrée en assumant que les niveaux acoustiques moyens persistent tout au long de la période de 8 heures et que des bouchons d'oreilles ne sont pas utilisés. Cette figure suggère que la moitié de la population des mineurs n'est pas protégée au niveau légal requis. Toutefois, aucune de ces deux hypothèses n'est vraie et il est fort probable qu'une proportion largement supérieure à la moitié se trouve protégée au niveau requis. La principale raison de la faible performance des protecteurs supra-auriculaires en pratique découle d'un mauvais ajustement, la force du ressort étant souvent inadéquate, principalement chez les individus ayant un faible tour de tête. L'emphase a été mise sur la mesure et le contrôle de la force de serre et le besoin d'ajuster les supports des protecteurs au tour de tête. Des recommendations basées sur ces relevés ont donc été faites, afin d'améliorer les programmes de contrôle pour la protection de l'ouïe.

Les relevés sonores constituent un recueil d'informations. Les relevés détaillés, utilisant la technique d'enregistrement des données, constituent l'essentiel des volumes 3 et 4, et contiennent de l'information précieuse pour tous ceux qui entreprennent des programmes de contrôle du bruit dans des opérations minières. Près de 700 jours-hommes ont été enregistrés lors des relevés détaillés. Il est ainsi possible de constater que la distribution d'exposition des mineurs au bruit varie, au cours de la période de travail, de presque constante à très variable. Dans les mines, 262 des 432 périodes de travail enregistrées l'ont été à l'aide de l'audio-dosimètre en niveau relatif à l'exposition permise. Les valeurs les plus fortes indiquaient un dépassement du seuil de 40 fois, signifiant une protection de l'ouïe de l'ordre de 28 dBA d'atténuation. Cette atténuation serait encore supérieure si les nouveaux standards proposés par OSHA étaient utilisés comme base au lieu des règles actuelles (au moment où les rapports étaient rédigés). Dans les usines et ateliers de surface, seulement 13 des 250 périodes de travail enregistrées l'ont été à l'aide de l'audio-sonomètre. La valeur la plus forte requerrait une atténuation de l'ordre de 10 dBA pour assurer la protection légale de l'ouïe.

Les travaux de contrôle du bruit ont été entrepris sur des foreuses à percussion de poids léger à moyen, sur les foreuses à diamant et sur les systèmes d'échappement des moteurs diesels. Les études sur les foreuses à diamant ont démontré un besoin d'investigation approfondie de toutes les sources de bruit, quatre sources majeures ayant été identifiées. La réduction d'une seule source résulterait en une atténuation à peine discernable du niveau acoustique moyen, à savoir 1 dBA. Elle pourrait cependant modifier la qualité sonore de façon appréciable.

Les niveaux sonores élevés mesurés dans les mines mettent l'emphase sur le besoin de travaux importants, afin de réduire le bruit du matériel minier. Il est probable qu'il faudra éventuellement limiter l'exposition des travailleurs à des bruits n'excédant pas 85 dBA et que l'usage de protecteurs auriculaires devienne une condition de travail indésirable, à éliminer.

L'étude contractuelle sur les vibrations a démontré que les foreuses manuelles verticales et sur béquille exposaient le mineur à des niveaux vibratoires suffisants pour induire le phénomène de Raynaud (insensibilité de la main) chez plus de la moitié de la population sur une période allant de 1 à 4 ans. Elle a aussi permis de démontrer que les isolants vibratoires permettent de réduire la transmission des vibrations à la main et suggéré de développer des poignées isolant les vibrations et de les adapter aux foreuses à percussion. Ces relevés ont aussi identifié des sites où les vibrations corporelles excédaient les directives dans les usines et ateliers de surface. Les véhicles souterrains à moteur diesel ne furent pas examinés.

Le rapport 73-17, dans la section "divers" du volume 6 expose bien les problèmes de bruit et vibrations dans les mines. Les sujets abordés sont la mesure du bruit et des vibrations, les standards d'exposition au bruit et aux vibrations, les sources de bruit et de vibrations, et les méthodes de contrôle.

Il faut enfin mentionner que plusieurs des rapports couvrent plus d'un sujet et qu'ils n'ont pas de renvoi mutuel. Ils sont inclus dans le manuel qui correspond au principal aspect étudié.

Les pages des rapports n'ont pas été renumérotées. Pour mieux localiser chaque rapport, une page rouge est insérée au début de chacun. Chaque rapport est numéroté dans le coin supérieur droit et contient, en plus, son titre propre et la description du contenu, ainsi que son lieu d'édition lorsqu'il ne s'agit pas d'un rapport divisionnel. Un résumé français est compris avec chaque rapport.

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VOL. 6 Report 1

VOLUME 6 - VIBRATION STUDIES
— ÉTUDES DES VIBRATIONS

S.G Hutton

A study of vibration sources

affecting mine workers

Contract Report 83-09SU, 23440-1-9133

Scientific authority M.U. Savich 1983.

RESUME

Le présent document décrit une étude menée pour évaluer (i) les caractéristiques des sources de vibrations qu'on trouve dans les environnements miniers et (ii) les instruments actuellement disponibles pour les mesurer. Des résultats sont présentés pour des marteaux-stopers et des marteaux à béquille et pour des niveaux de vibrations dans l'organisme entier dans des salles d'affinage et de compresseur. Des essais ont été menés dans deux grands centres miniers, et des données suffisantes ont été obtenues pour déterminer les signatures des vibrations caractéristiques des marteaux-perforateurs. On établit des comparaisons et recommande des étalons de contrôle de la maladie des doigts blancs due aux vibrations.

On fait état d'essais de laboratoire où on propose des approches pour réduire les vibrations dans les poignées des marteaux-perforateurs. On vérifie les instruments existants et on fait état de l'opération d'interfaçage d'un enregistrement particulier par ordinateur.

ABSTRACT

This work describes a study conducted to evaluate (i) characteristics of vibration sources found in a mine environment and (ii) instrumentation presently available for their measurement. Results are presented for jack leg and stoper drills and for whole body vibration levels in refiner and compressor room areas. Tests were conducted at two large mine sites and sufficient data were obtained to determine characterisic rock drill vibration signatures. Comparisons are made with the recommendation of Standards concerning the development of Vibration White Finger Disease.

Laboratory tests are reported that consider approaches whereby rock drill handle vibration levels may be reduced. Existing instrumentation is tested and the task of computer interfacing a particular data recorded is reported.

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1. BACKGROUND

Prolonged exposure to high levels of vibration has been recognized for many years as a potential hazard to health. A preliminary account of the effect of vibration on workers in the mining industry and an assessment of vibration levels to which miners are exposed can be found in a recent report to CANMET carried out at the University of British Columbia by S.G. Hutton and R.L. Brubaker [1]. The major effect of vibration on workers is injury to the hand and arm. Amongst miners, operators of hand held pneumatic drills are the principal workers affected. The general term used to describe the injury to the hand and arm is Vibration White Finger Disease (VWFD).

There have been a number of studies reported on the development of VWFD amongst rock drillers and other users of pneumatic hand held tools. Countries where studies have been carried out include Norway, Sweden, Japan, Great Britain, Denmark, Italy, Poland, France and Canada. Prevelancy rates for VWFD in these studies varies from 20.9 to 91%. The prevalence rate of VWFD among miners in Canada is unknown. With the exception of reports of VWFD among uranium miners in Northern Saskatchewan in the 1960's, there has been little information available to judge the extent and severity of this problem in Canada. Reference (1) summarized the information available as of 1980.

In Canada, as in many other countries, there is presently no existing standard to regulate vibration exposure from hand held mining equipment.

There is, however, an International Standards Organization Draft Proposal entitled: "Principles for the Measurement and Evaluation of Human Exposure to Vibration Transmitted to the Hand" (ISO DIS 5349) which is being cosidered for adoption in Canada. It is worthy of note that the vibration levels of pneumatic drills presently in use in the mining industry are such, according to this Standard, as to produce symptoms of VWFD after a relatively short exposure time.

Although the problem of whole body vibrations would appear to be less acute from an injury viewpoint, problems associated with loss of worker efficiency have been recognized. The international standard ISO 2631 "Guide for the Evaluation of Human Exposure to Whole Body Vibration" prescribes vibration limits above which decreased worker proficiency may be expected. It can be anticipated that some mine workers will be exposed to such levels.

2. PURPOSE

The purpose of this work was to study the major effects of vibration upon Canadian mine workers. To this end it was necessary to obtain quantitative data representing actual exposure conditions, to make comparisons between the results obtained and relevant standards, and to assess the applicability of existing instrumentation. The report also briefly considers how the excessive vibration levels produced by rock drills may be reduced. The work was thus divided into three distinct parts:

(i) Field Tests

The purpose of the field tests was to obtain, directly from a working environment, tests results that would characterize accurately the level of vibration that miners are exposed to. Of primary concern is the vibration of hand held rock drills. Thus the major aim of the field tests was to obtain sufficient data on vibration levels of jack leg and stoper drills to enable an accurate picture of the vibration characteristics of such drills to be formed. In this regard it was required to investigate specifically the effect of such variables as drill type, manufacturer, steel length, and air pressure; and to determine the level of accuracy with which such vibration results could be repeated. As is well recognized, rock drill vibration can cause VWFD, and a further purpose of this work was to compare the results obtained with the specifications of relevant Standards.

It was also required to obtain levels of whole body vibration that other mine workers are subjected to. Such levels are of interest primarily in terms of reduction of worker efficiency rather than concern over health aspects.

A final purpose of the field testing was to evaluate the suitability of existing instrumentation to the needs of the Canadian mining industry.

(ii) Laboratory Tests

The purpose of this portion of the work was to investigate the possibility of reducing the vibration level of hand held rock drills using relatively simple techniques. The intent was to test the effect of vibration absorber and isolator concepts on a production rock drill with a view to developing, in the future, mechanisms for reducing vibration levels that do not require a major redesign of the drill.

During laboratory testing it was also required to evaluate the suitability of instrumentation designed specifically to measure hand arm vibration.

(iii) Computer Interfacing of Existing Instrumentation

With the widespread availability of computers and the ease with which they can process and display large amounts of data it is desirable that any data gathering system be capable of interfacing to a computer. The purpose of this part of the study was to consider how existing instrumentation could be so interfaced.

3. FIELD TESTS

3.1 Introduction

Although it has been recognized for some time that the vibration levels produced by hand operated rock drills such as those used in Canadian mining operations may be excessive, up to the present time very few vibration measurements have been conducted on such drills. Hutton and Brubaker [1] summarized the work that had been reported in the area up to 1980. The International Standards Organization revised their draft international standard ISO DIS 5349 "Guide for the measurement and assessment of human exposure to vibration transmitted to the hand" in September 1982 basing these revisions upon existing data. Representative field tests are required to evaluate the validity of the standard to Canadian drilling conditions.

The primary aim of the present field testing was to measure vibration levels of rock drills during actual drilling conditions. Such measurements are difficult to obtain. As well as the logistical problems of conducting tests in production mine environment, the instrumentation required to obtain reliable results was not designed for the rugged, wet, and dusty conditions found underground in a mine. Thus, it is not altogether surprising that there is a dearth of such experimental records. The specific aims of the field testing program were to:

(i) obtain vibration data pertaining to different types of drills commonly used by Canadian miners and to compare their respective vibration characteristics. Such data will be valuable in considering design changes that may help reduce vibration levels;

(ii) obtain data as specified in ISO DIS 5349 that could be used to investigate the implications of the standard with respect to Canadian miners. Such data includes the exposure dose to which miners are subjected;

(iii) obtain quantative data of the effect of such operating factors as steel length, air pressure, rock type and support condition upon the vibration levels produced by rock drills;

(iv) obtain characteristic whole body vibration data for workers in refining and compressor areas.

Two large underground mines were visited:

(a) Westmin Mine, Vancouver Island, British Columbia, and

(b) Sullivan Mine, Kimberley, British Columbia.

3.2 Instrumentation and Data Processing

Measurements were conducted in the field using an accelerometer Bruel and Kjaer(B&K) 4370 or 4339), a B&K 2635 preamplifier, and a B&K 7003 tape deck. For the rock drill tests single axis readings were taken in the direction of drilling by attaching the accelerometer directly to the handle of the drill via a mechanical filter B&K UA0559 using a hose clip. On the hose clip a mount had been soldered onto which the mechanical filter was screwed. Calibration levels were recorded on the tape using a B&K 4291 accelerometer calibrator. During rock drill testing all the connections and the accelerometer were bound with tape to prevent water and dust affecting the connections. The tape deck and preamplifier were contained in a plastic bag. Despite these measures some difficulties were still encountered. Without adequate attention to such details invalid results may easily be obtained.

The tape recorded data was subsequently analyzed by a Nicolet 660A spectrum analyzer to produce a RMS acceleration record over the interval 0-2000 Hz. This spectrum was then fed into a PDP 11-34 computer for statistical analysis, plotting and weighing according to the relevent standard. The graphical plots were produced by a Tektronix 2663 digital plotter and a Tektronix 4051 graphics terminal.

3.3 Results of Rock Drill Tests from Westmin Mine

Measurements were taken underground at the location that the miner was working that particular day. The vibration level was recorded on the tape deck for the time it took to drill a complete hole - approximately 2 minutes for each 4 ft. of penetration. On average four distinct records were recorded for each drill, although in some cases it was only possible to obtain one such record. Each different record represents either a different length of steel or a different hole being drilled. In the data quoted each different sample represents an average of 16 results taken from a different record. During such tests the drill type, number, length of steel, support conditions, air pressure and drilling time were recorded.

In order to present the large volume of results obtained in an understandable form two types of graph have been used in addition to individual spectra. In the first; the mean, maximum, and minimum values of a set of spectra have been presented and in the second the mean and standard deviations are given. These plots were obtained by calculating at each frequency point the mean, maximum, and minimum values recorded for that set of spectra. As such therefore the plots do not themselves represent measured spectra. In accordance with ISO DIS 5349 spectra were recorded over the frequency interval 5-1500 Hz and the value of RMS acceleration has been quoted in metres/sec^2.

At the Westmin mine the jack leg drill is more commonly used than the stoper and at this mine 14 jack leg drills, 5 stopers, and 2 long toms were measured. Virtually all the drills used were made by the same manufacturer and they will be referred to as type B.

In Figures 3.1a-d are presented the spectra obtained for one jack leg (using a 6' steel) using 4 different samples (4S). These samples were obtained in this case by drilling two holes with the samples being taken from the start and end of each record. In Fig.3.1a the mean, maximum and minimum values are presented for the frequency range 5-1500 Hz, and in Fig. 3.1b for the range 5-100 Hz. Dominant peaks occur at approximately 37 Hz and 225 Hz. The peak at 37 Hz and its harmonics can be attributed to the firing action of the pneumatic drill. The peaks at 225 Hz are likely to be associated with internal resonances within the drill. From the view point of vibration white finger disease (VWFD) it should be noted that low frequency accelerations are the most significant according to ISO DIS 5349. In this standard acceleration at frequencies above 16 Hz are weighted to the extent that at 40 Hz a weighting factor of approximately .3 is applied whereas at 225 Hz the weighting factor is close to .08. As may be noted from Figure 3.1b and d the recorded peak acceleration levels varied very little during this test, i.e., they did not vary from start to end of a given hole nor did they vary between different holes.

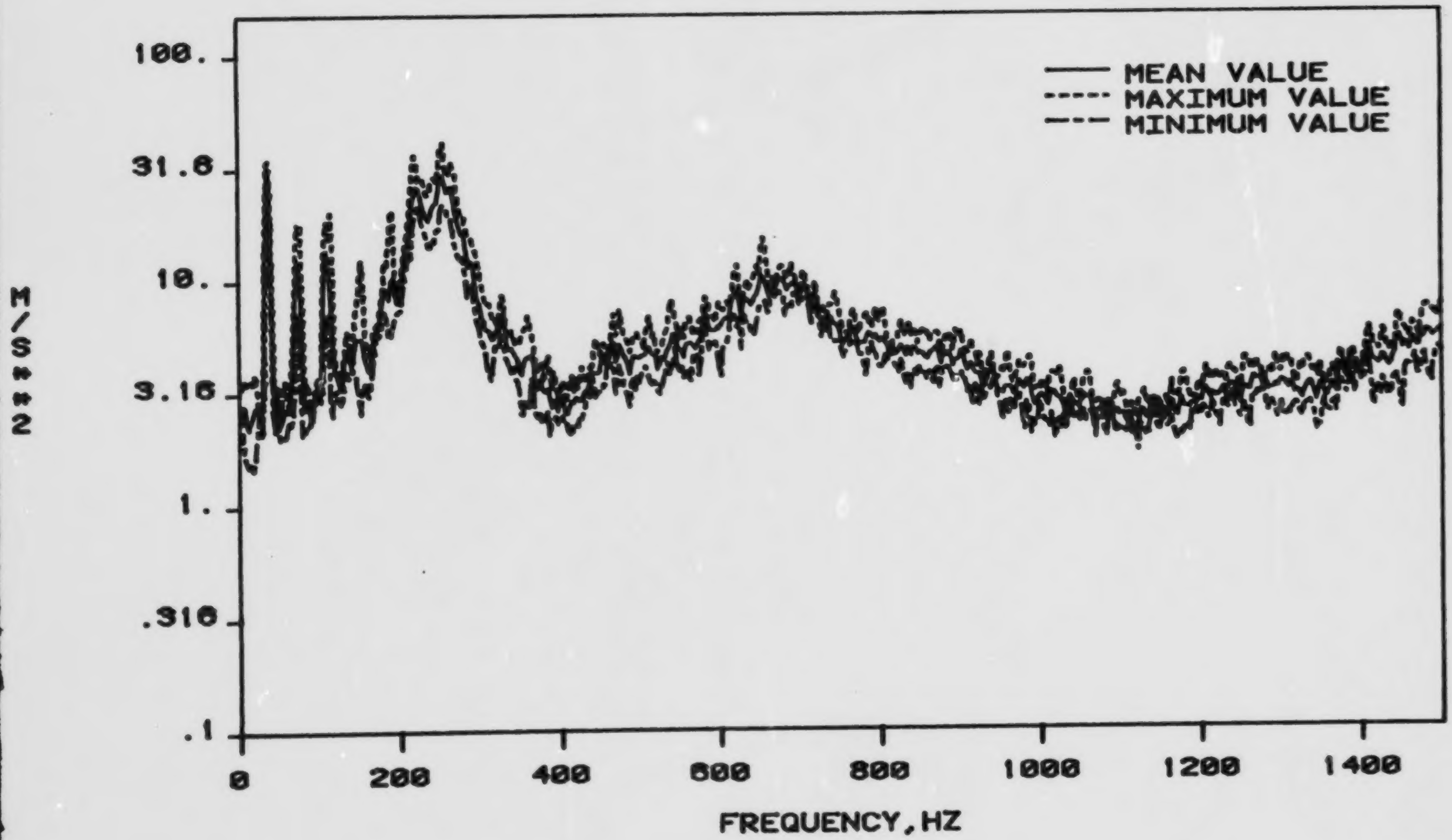


Figure 3.1a R.M.S. ACCELERATION SPECTRA FOR SINGLE JACK LEG DRILL (B, 4S)

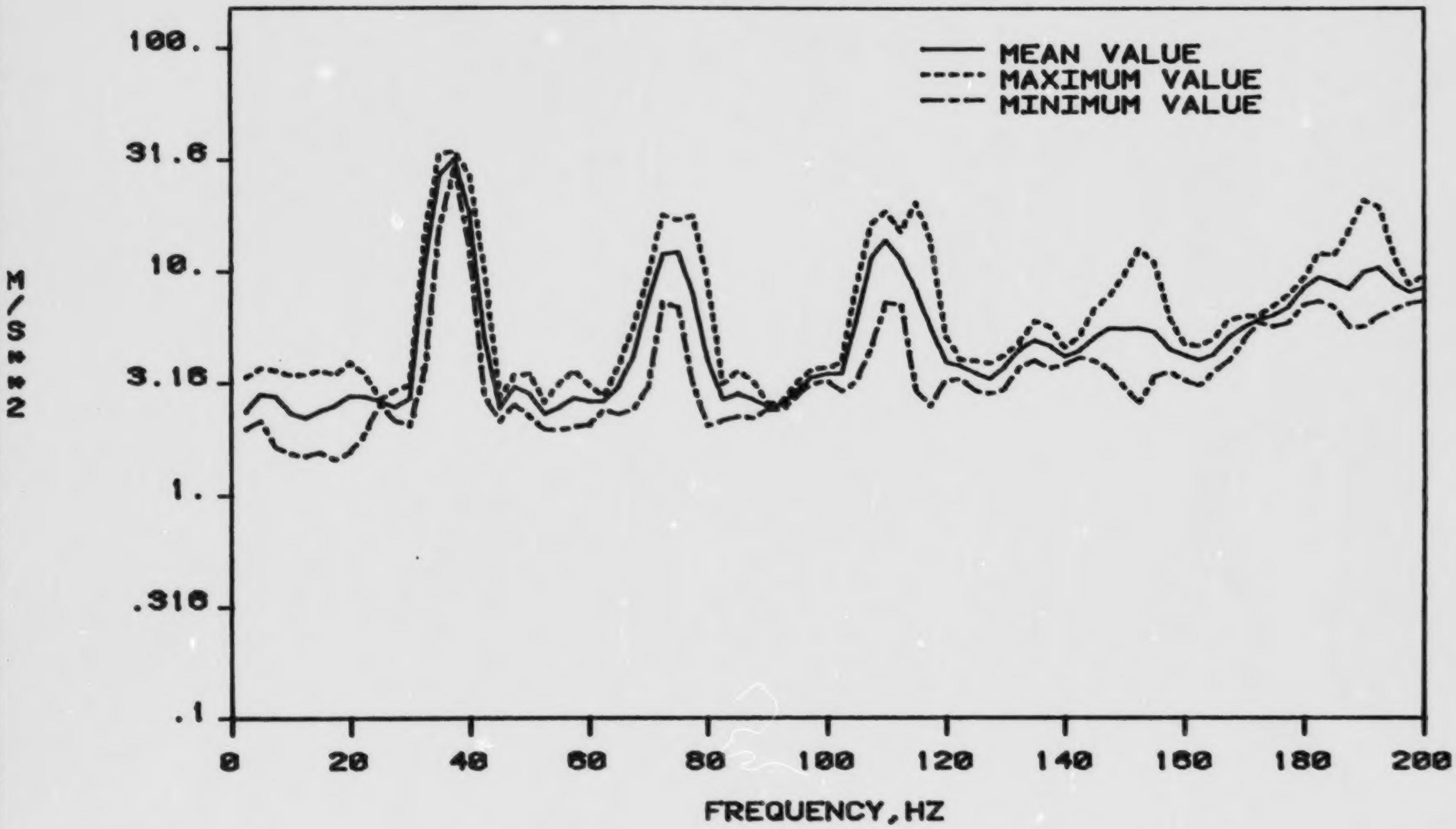


Figure 3.1b R.M.S. ACCELERATION SPECTRA FOR SINGLE JACK LEG DRILL (B,4S)

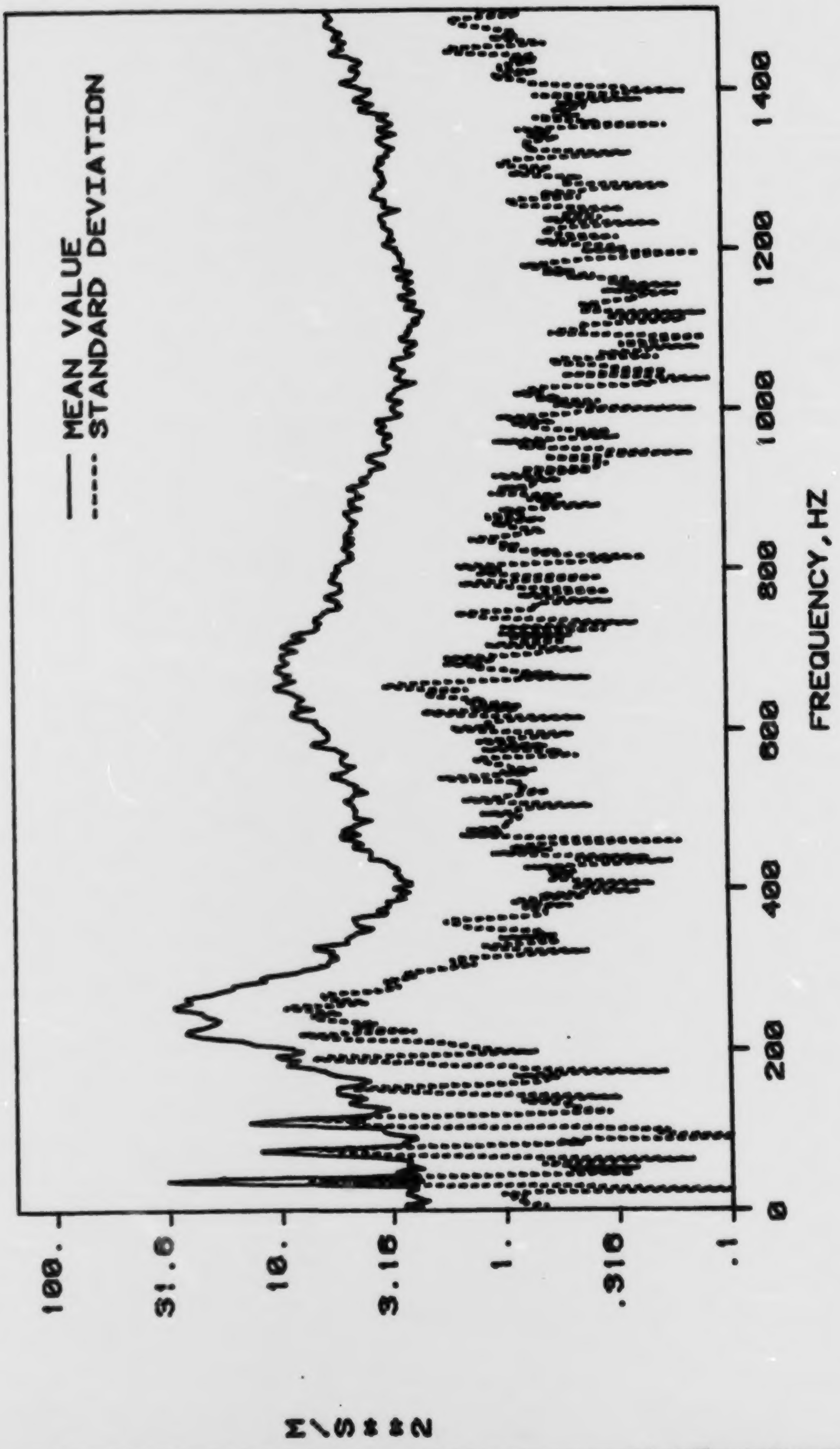


Figure 3.1c R.M.S. ACCELERATION SPECTRA FOR SINGLE JACK LEG DRILL (B,4S)

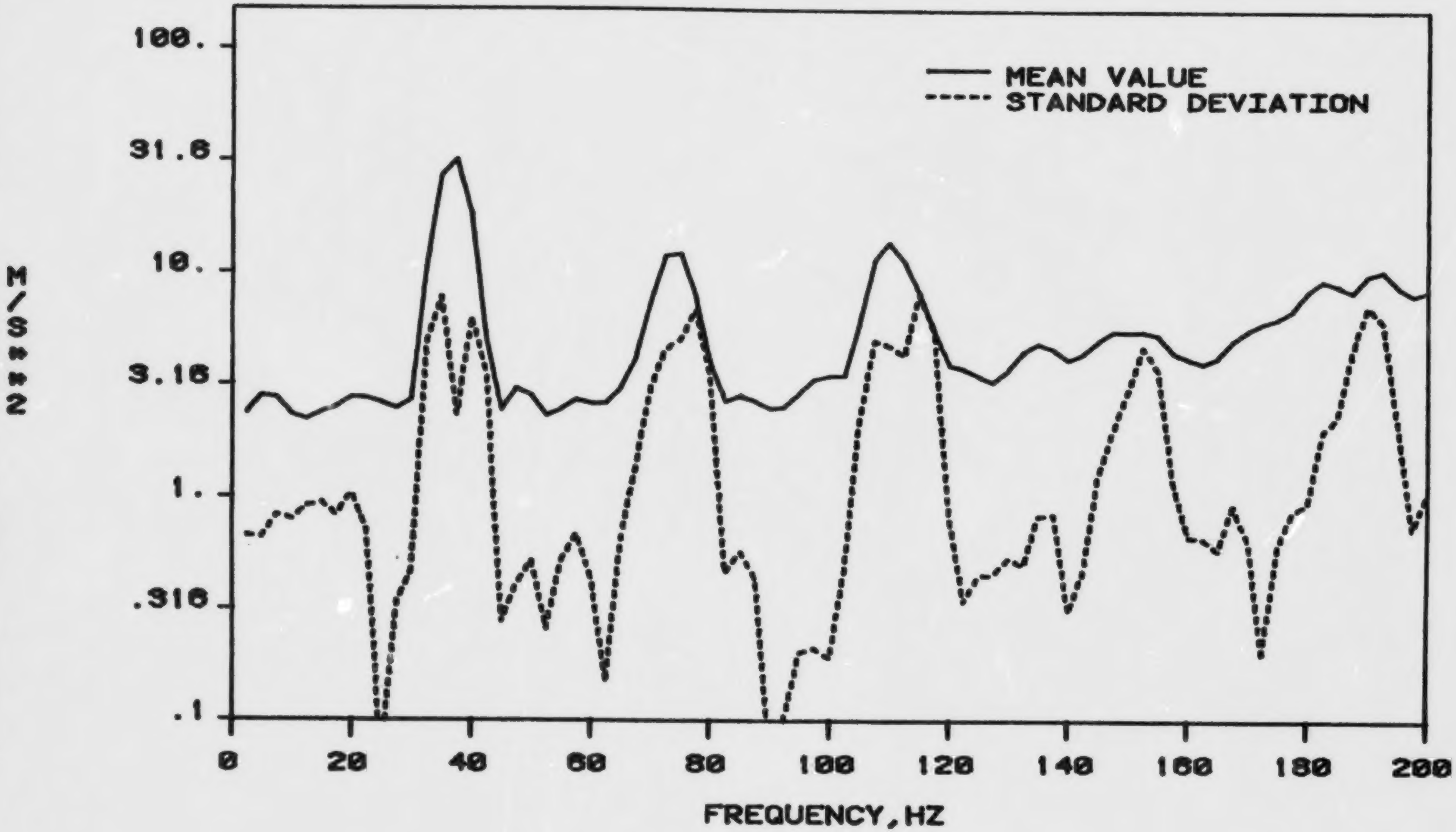


Figure 3.1d R.M.S. ACCELERATION SPECTRA FOR SINGLE JACK LEG DRILL (B,4S)

In Figures 3.2 a-d are presented the results pertaining to another particular jack leg drill. These results are based upon 3 samples taken from three different records. (In all future results different samples will be obtained from different records). Again the results may be seen to be highly repeatable with, in this case, all the major harmonics of the firing frequency giving the same peak levels for different samples.

The results displayed in Figures 3.1 and 3.2 indicate that sampled data taken from any point on the vibration record is representative of the whole record. In the above cases (and for all future cases) 16 averages were obtained to compute one sample spectrum. In both cases the drill used was the same model of type B. Thus in Figure 3.2 the (B,3S) refers to the fact that drill type B was used and that the graph represents the results from 3 samples (each taken from different records).

The mean spectra displayed in Figures 3.1 and 3.2 may be seen to have almost the same shape. In Figures 3.3 are presented the results of measurements conducted on 14 jack leg drills of type B. These results were obtained at different locations, using different steel lengths and drilling into different rock conditions. However, as may be noted the mean spectrum follows very closely those presented in Figures 3.1 and 3.2. This indicates that the drill has a well defined vibration spectra that is typical of that drill. Such a spectrum may be referred to as the vibration signature of the drill as it possesses an identifying characteristic for the drill. This result indicates that the drill signature is essentially independent of the operating variables that were involved in the tests

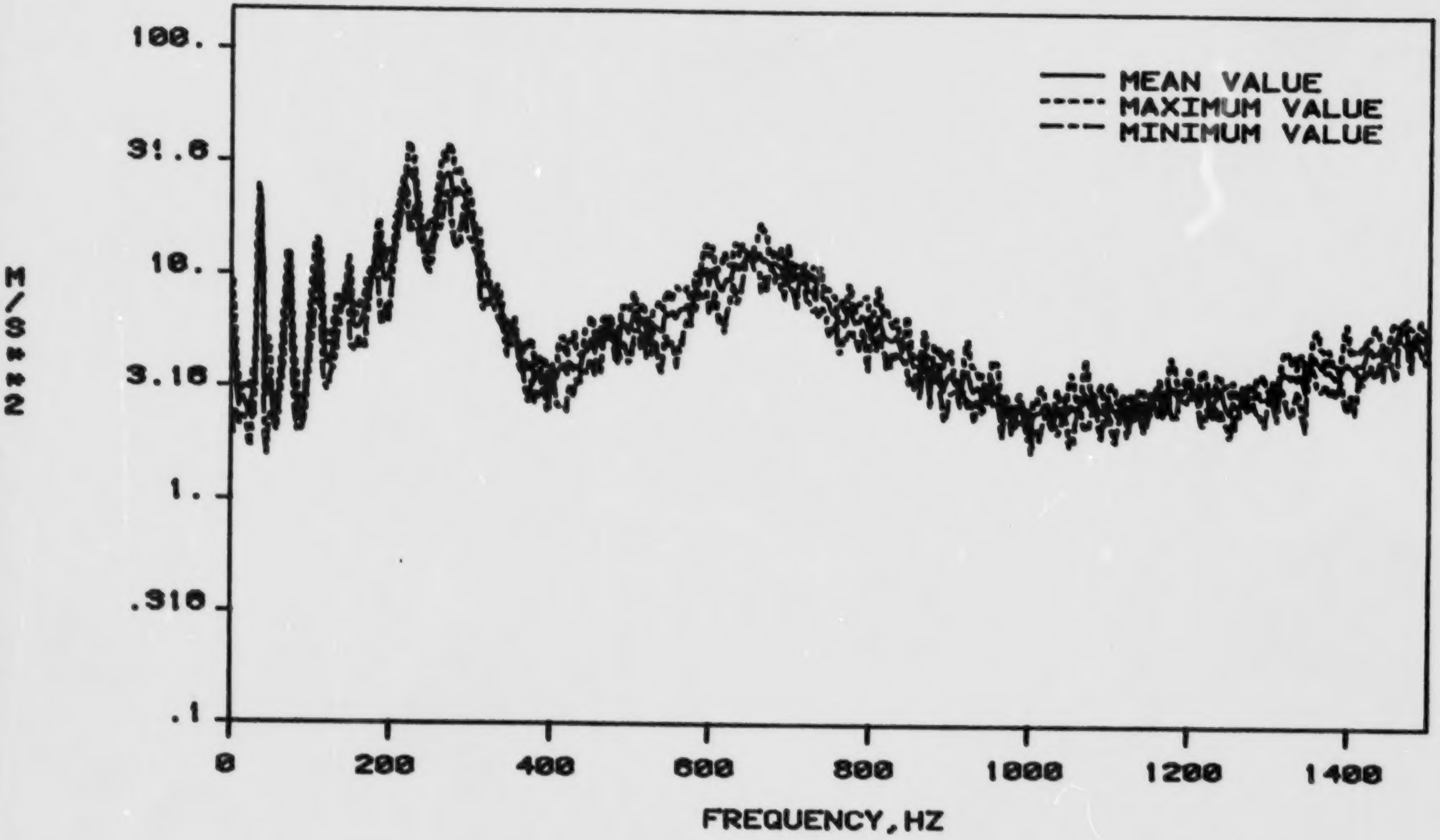


Figure 3.2a R.M.S. ACCELERATION SPECTRA FOR SINGLE JACK LEG DRILL (B,3S)

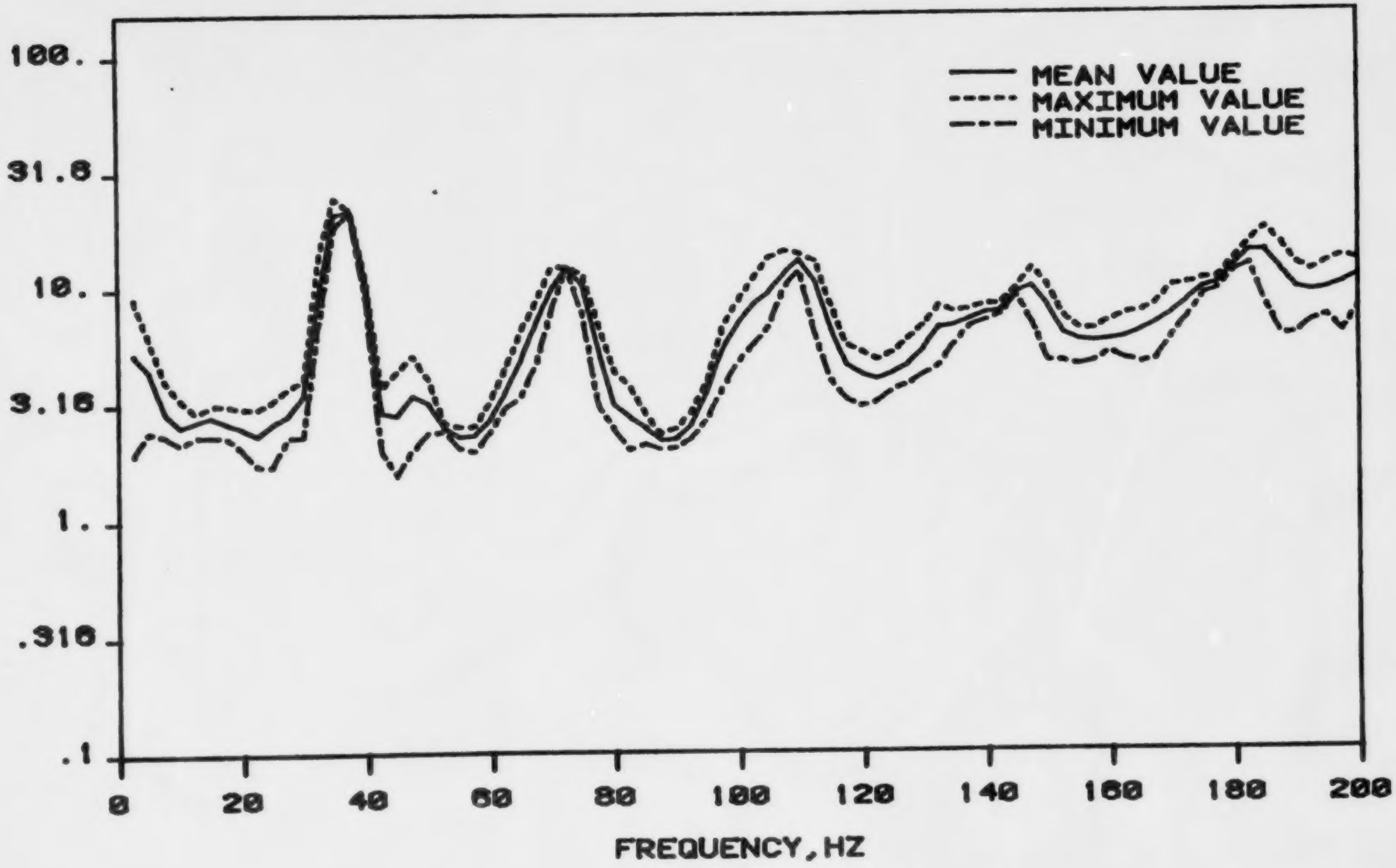


Figure 3.2b R.M.S. ACCELERATION SPECTRA FOR SINGLE JACK LEG DRILL (B,3S)

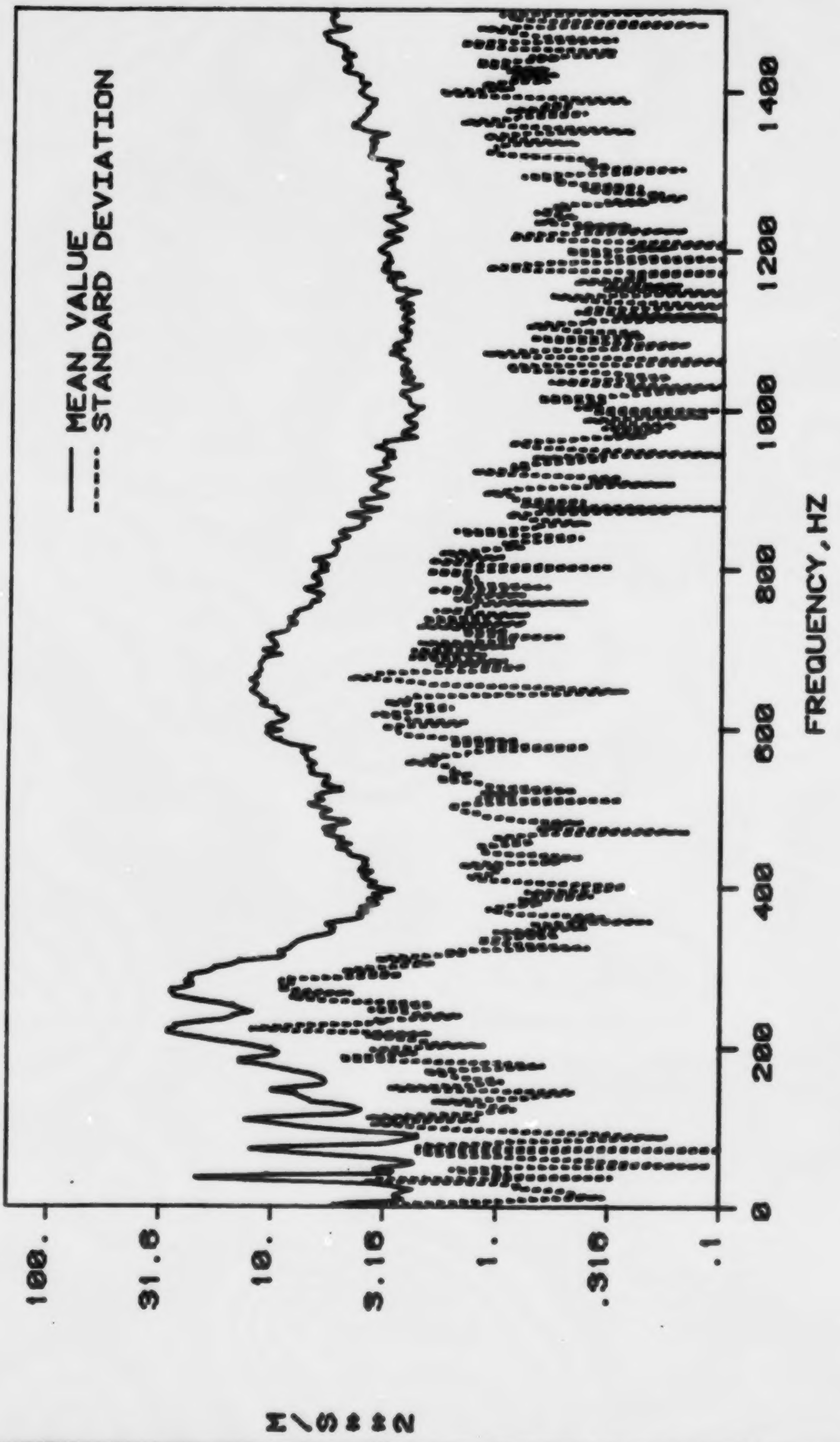


Figure 3.2c R.M.S. SPECTRA FOR SINGLE JACK LEG DRILL (B,3S)

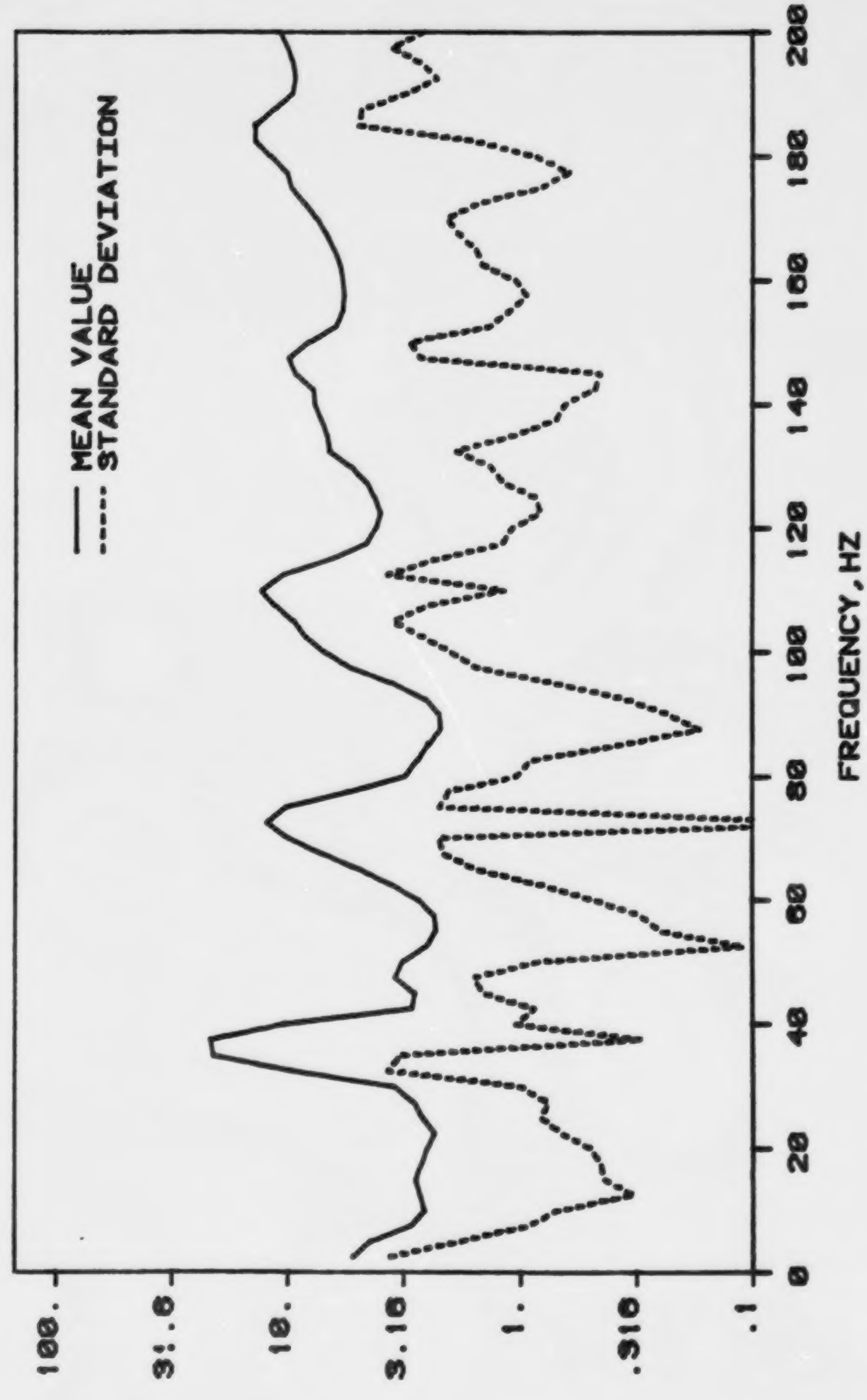


Figure 3.2d R.M.S. SPECTRA FOR SINGLE JACK LEG DRILL (B,3S)

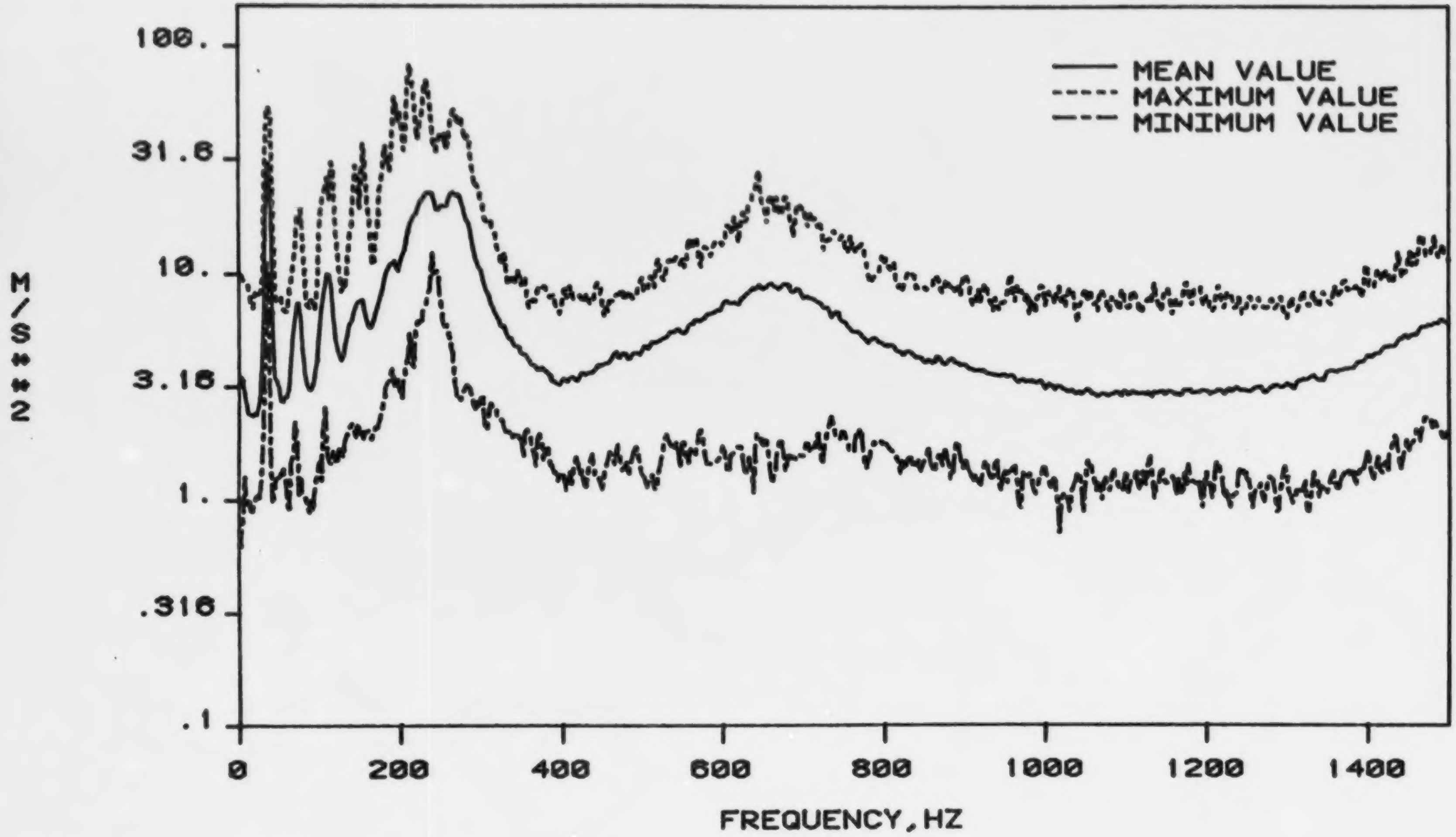


Figure 3.3a R.M.S. ACCELERATION SPECTRA FOR 14 JACK LEG DRILLS (B,39S)

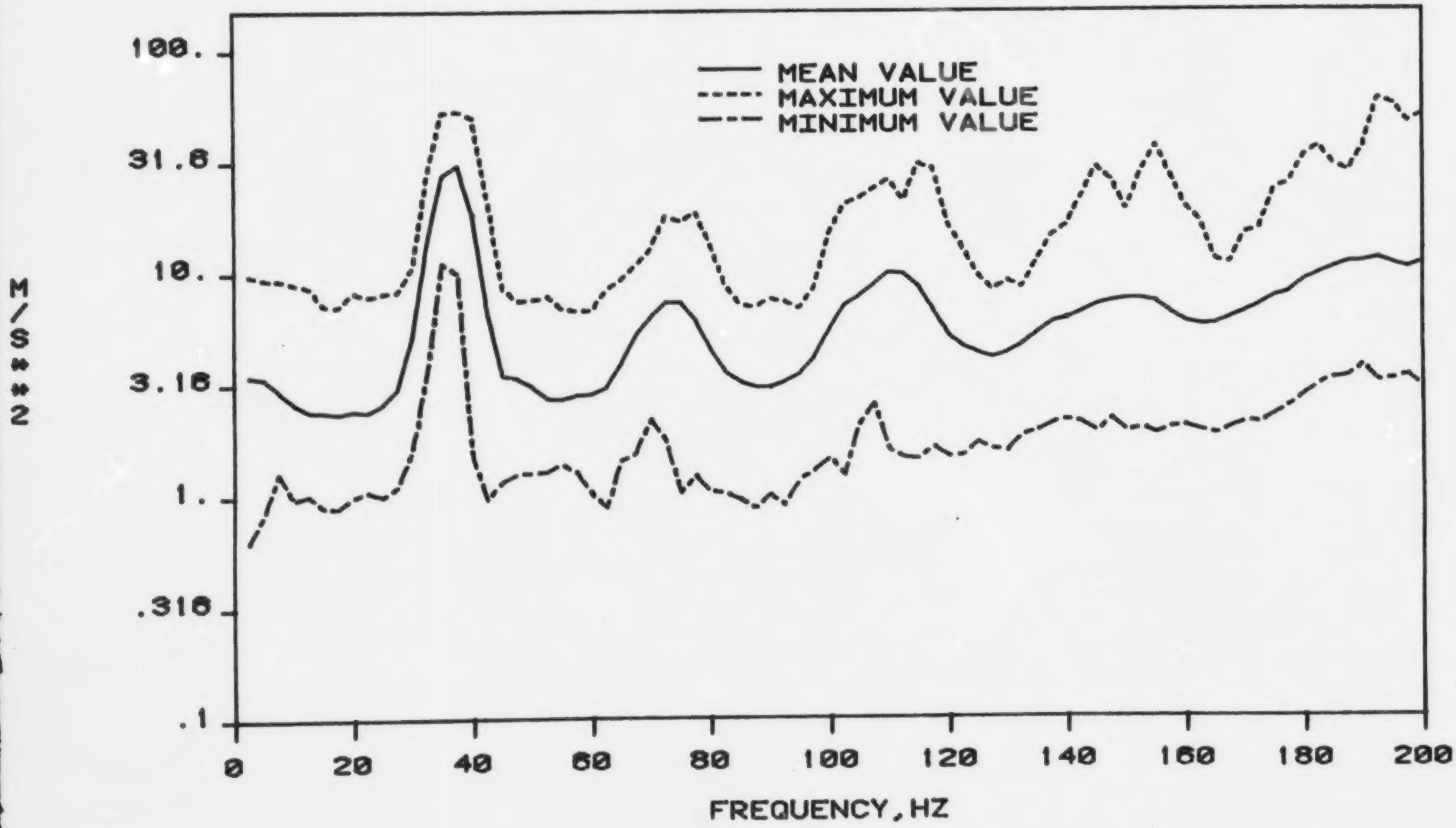


Figure 3.3b R.M.S. ACCELERATION SPECTRA FOR 14 JACK LEG DRILLS (B,39S)

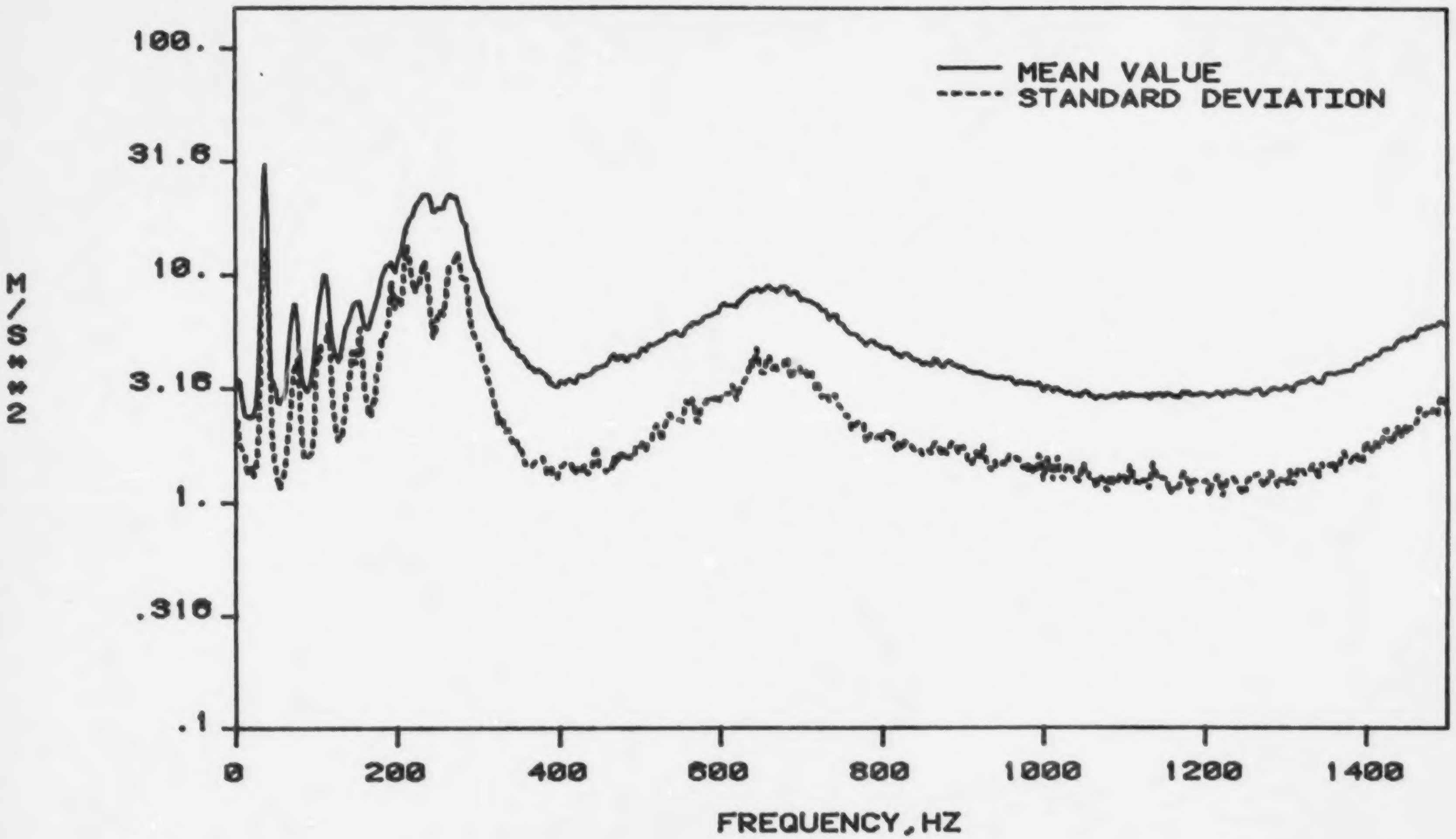


Figure 3.3c R.M.S. ACCELERATION SPECTRA FOR 14 JACK LEG DRILLS (B,39S)

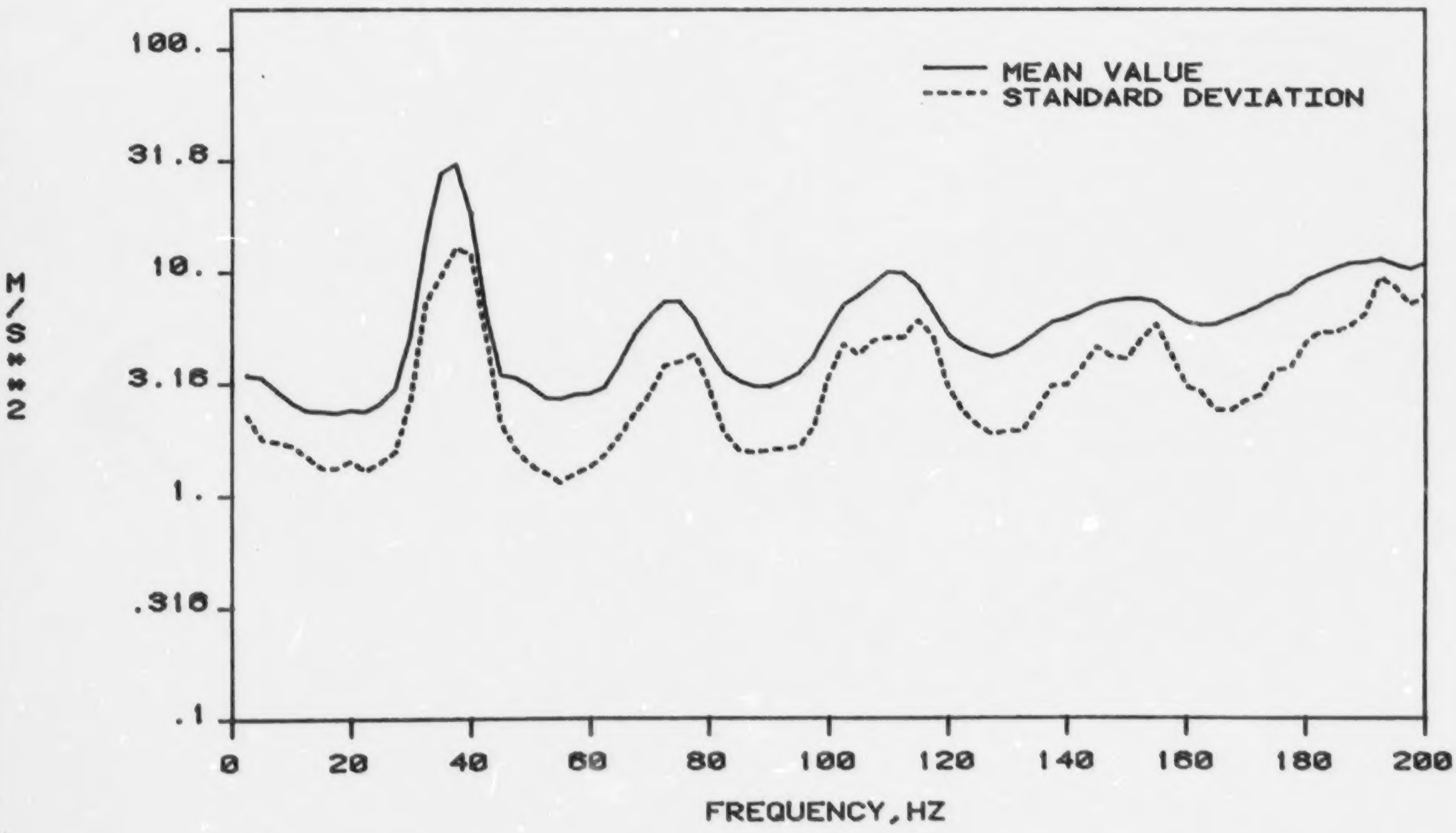


Figure 3.3d R.M.S. ACCELERATION SPECTRA FOR 14 JACK LEG DRILLS (B,39S)

conducted. As would be expected the variation involved between the vibration levels at any given frequency is much larger than for a test on a single drill. Accelerator levels at the firing frequency have a maximum value in excess of 50 m/s^2 with a mean value of 30 m/s^2.

Plotted in Figures 3.4a-d are the results obtained from a single jack leg of a different type (D). The vibration signature of this drill is somewhat different to that obtained for drill type B. A dominant peak at the firing frequency remains (at approximately the same level as for drill type B) but the spectrum shape above 200 Hz is quite different.

In order to investigate any possible effect of steel length on vibration levels, records were taken on 6 jack legs drilling with 4' steel (Figure 3.5) and for the same 6 drills drilling with 8' steel (Figure 3.6). A comparison of the mean levels obtained is presented in Figures 3.7a and b. The results do not indicate any significant dependence on steel length. Also, as none of the other results collected indicated any correlation between steel length and vibration level it was concluded that its effect could be neglected in terms of assessing vibration effects according to ISO DIS 5349.

In Figure 3.8 the results of tests conducted on 2 long tom drills of type B using 6 samples (E,2D,6S) are presented. The mean spectrum has the same general pattern as for the jack leg drill but with a lower peak at the firing frequency, and a significantly larger peak at 200 Hz.

In Figure 3.9 the results for a single stoper drill of type B; and in Figures 3.10 a-d the results of 38 samples taken from 5 stoper

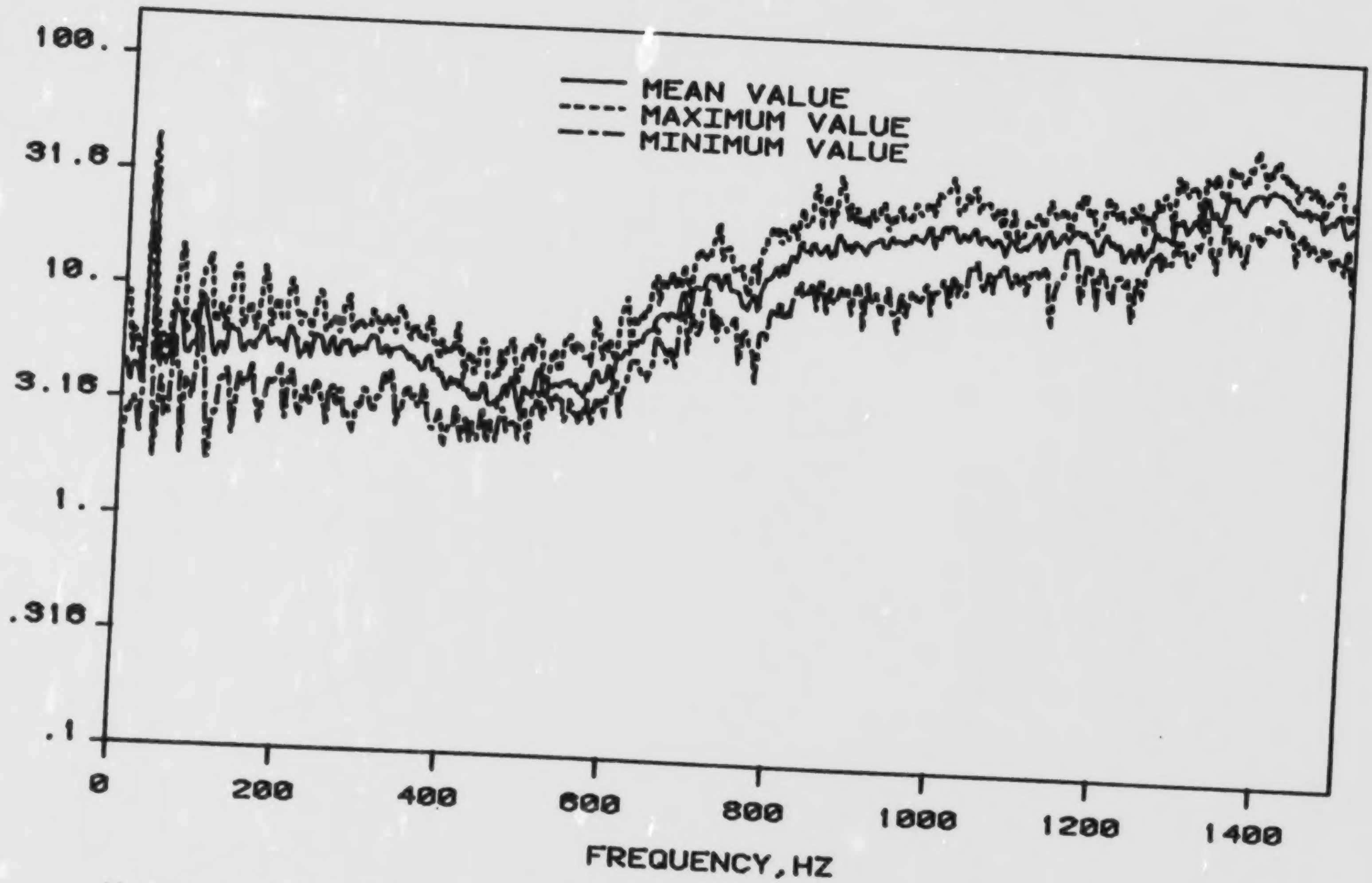


Figure 3.4a R.M.S. ACCELERATION SPECTRA FOR SINGLE JACK LEG DRILL (D,5S)

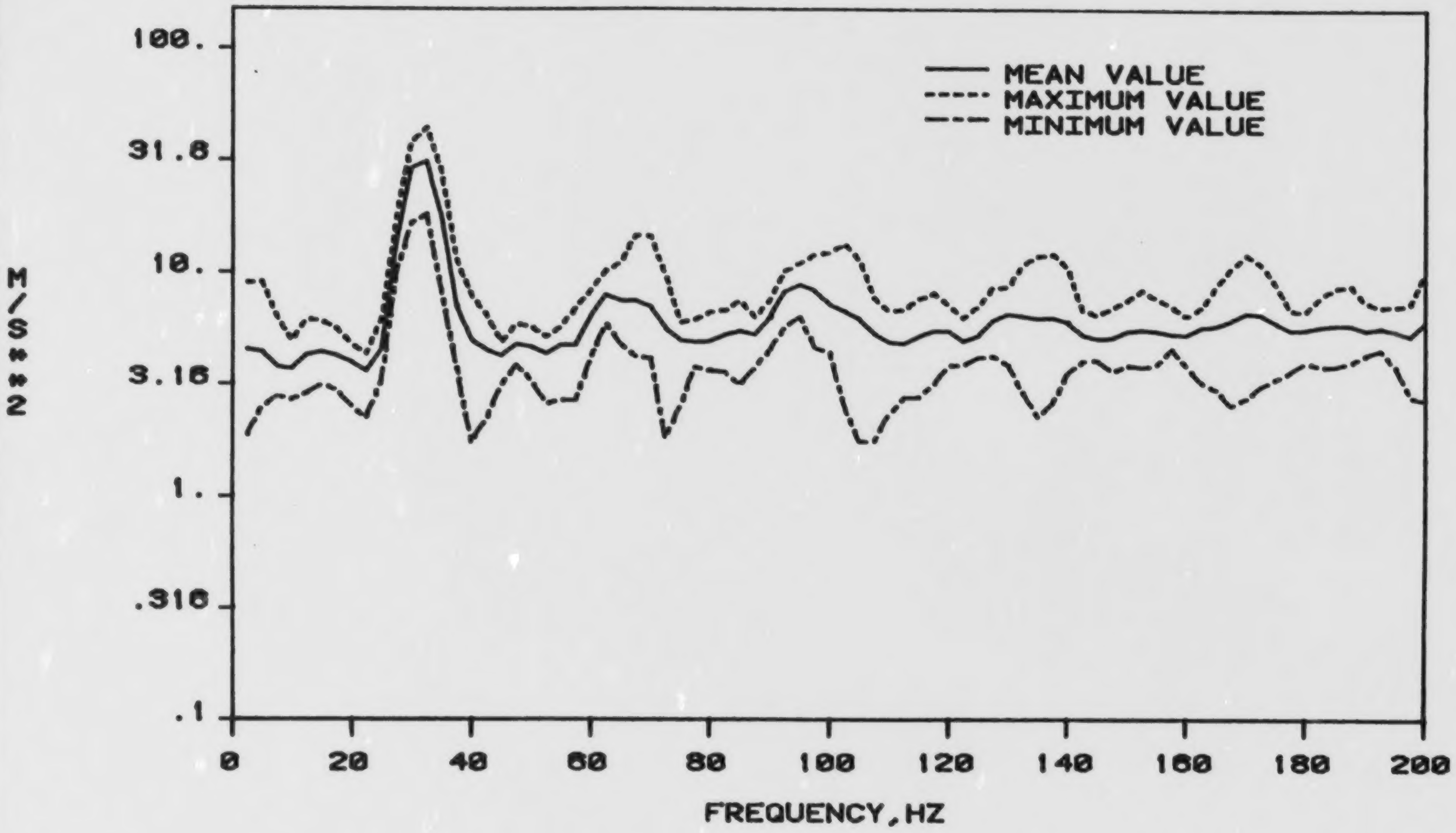


Figure 3.4b R.M.S. ACCELERATION SPECTRA FOR SINGLE JACK LEG DRILL (D,5S)

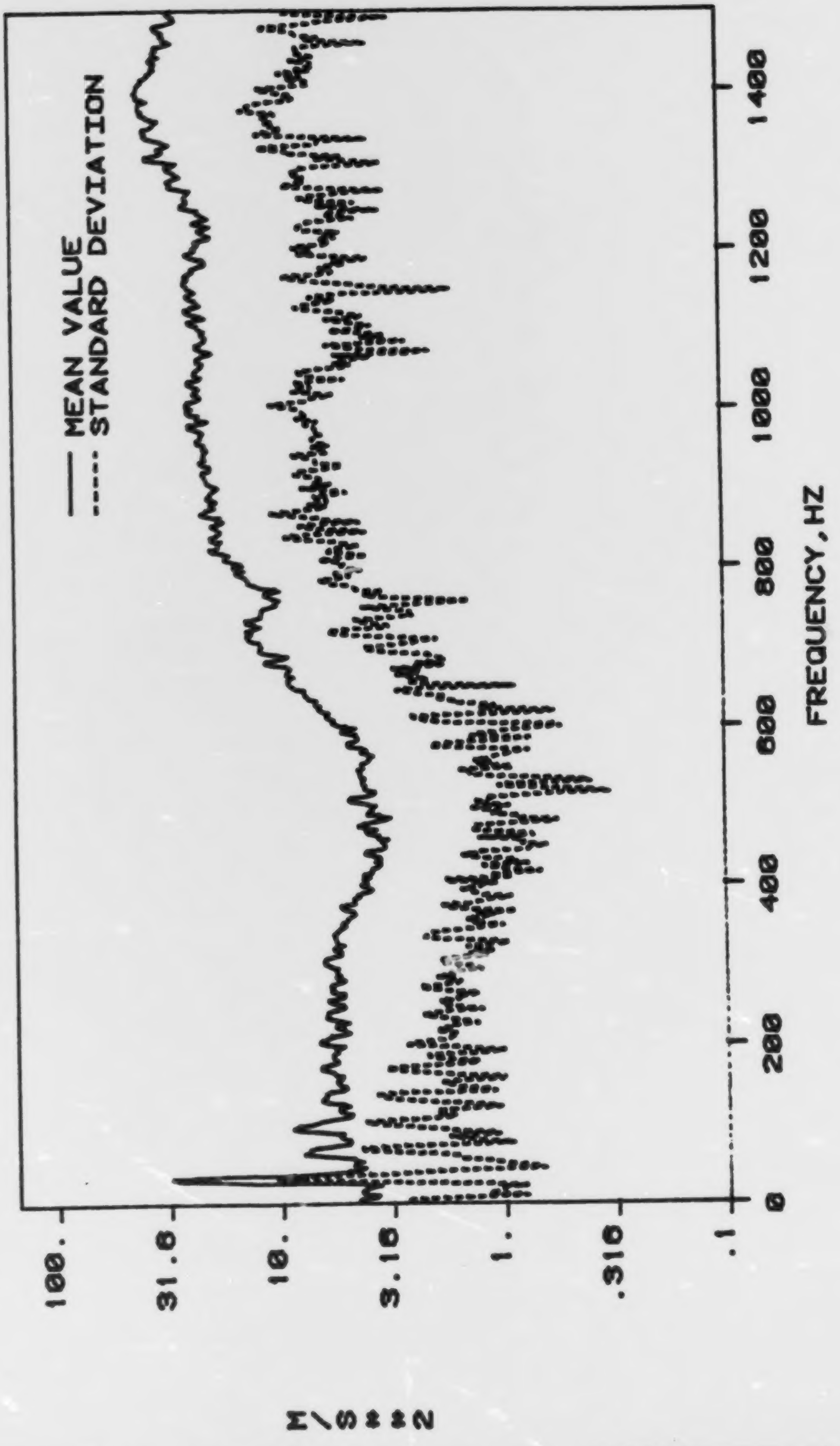


Figure 3.4c R.M.S. ACCELERATION SPECTRA FOR SINGLE JACK LEG DRILL (D,5S)

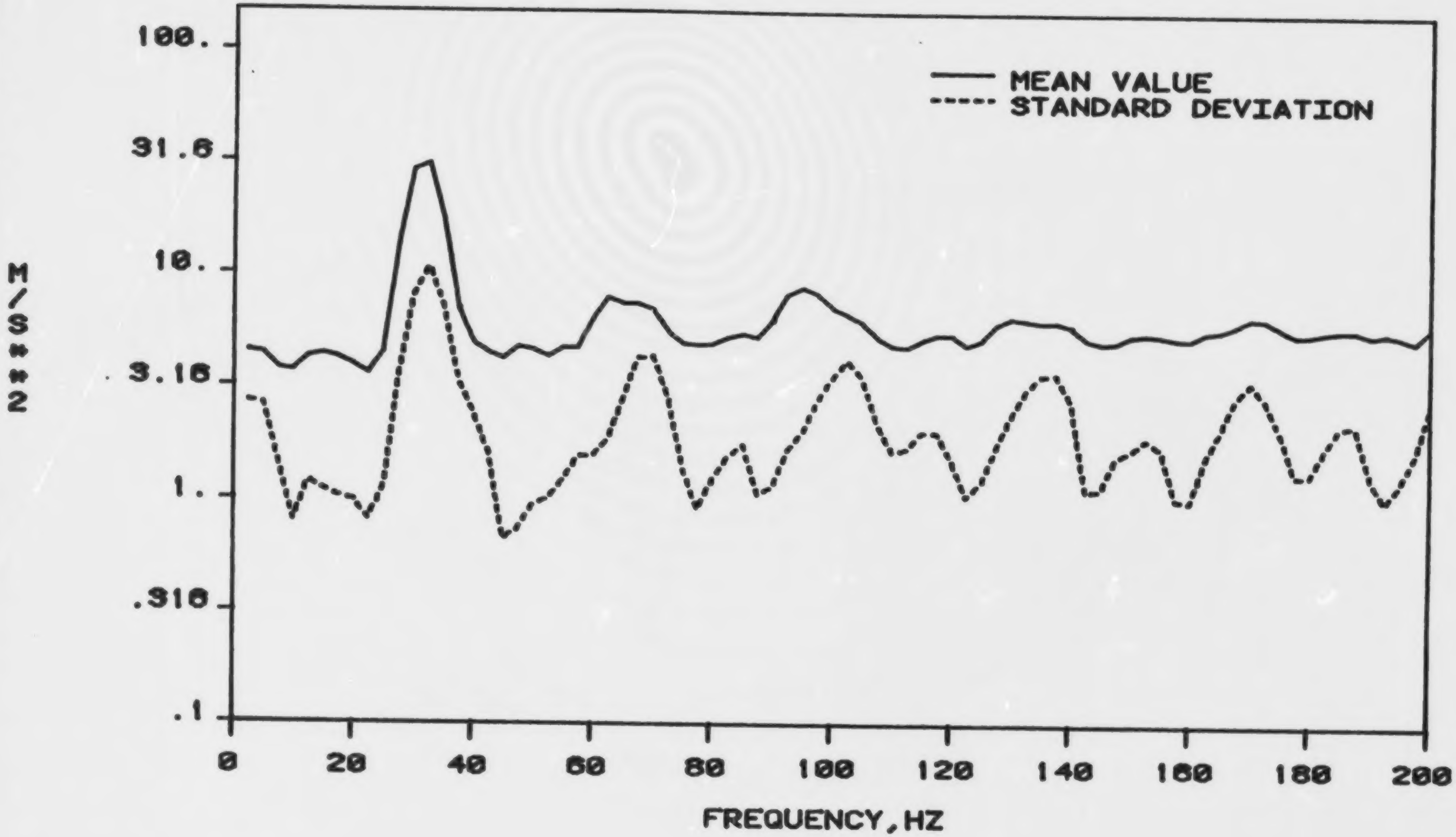


Figure 3.4d R.M.S. ACCELERATION SPECTRA FOR SINGLE JACK LEG DRILL (D,5S)

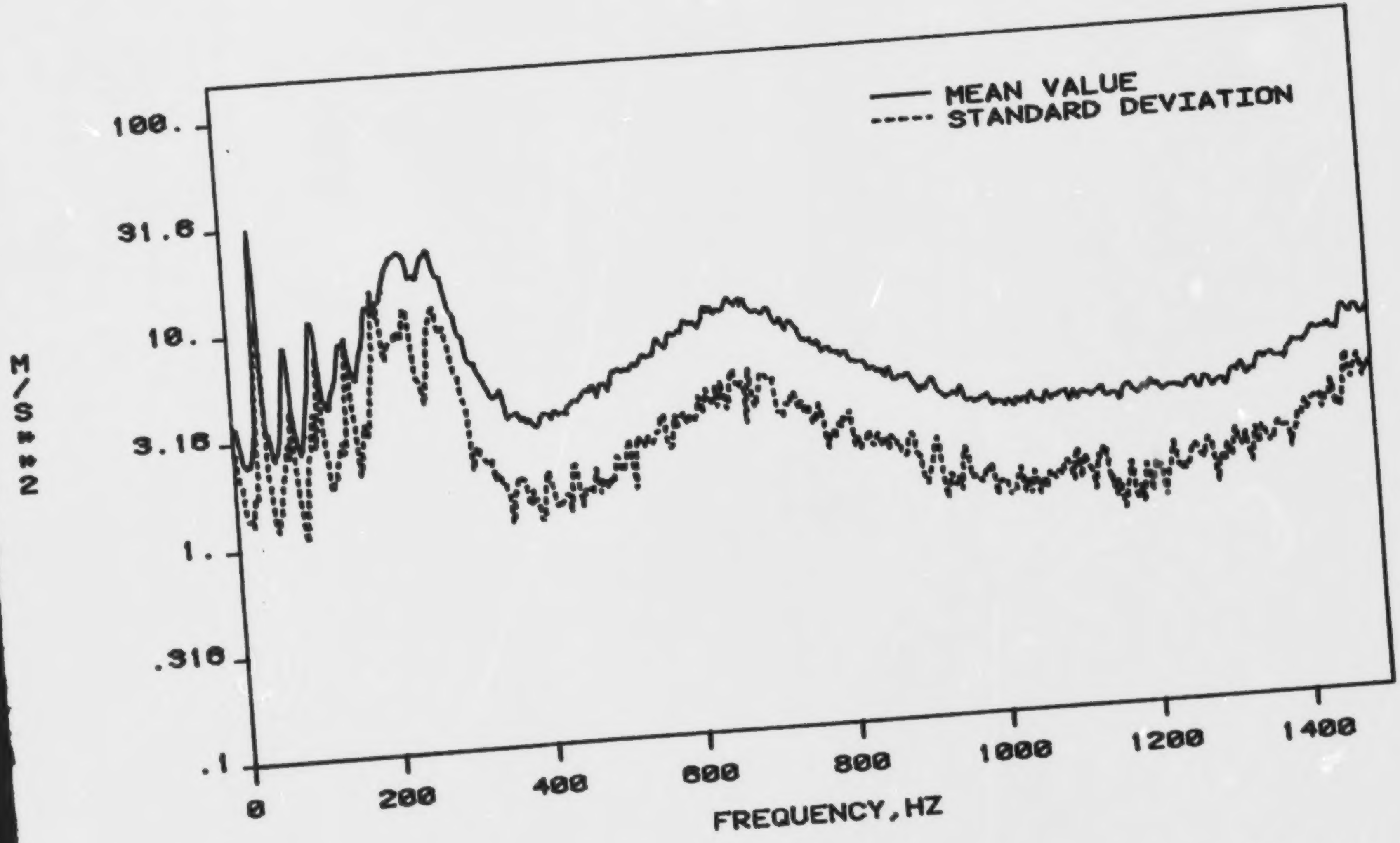


Figure 3.5 R.M.S. ACCELERATION SPECTRA FOR 6 JACK LEG DRILLS USING 4' STEEL (B,12S)

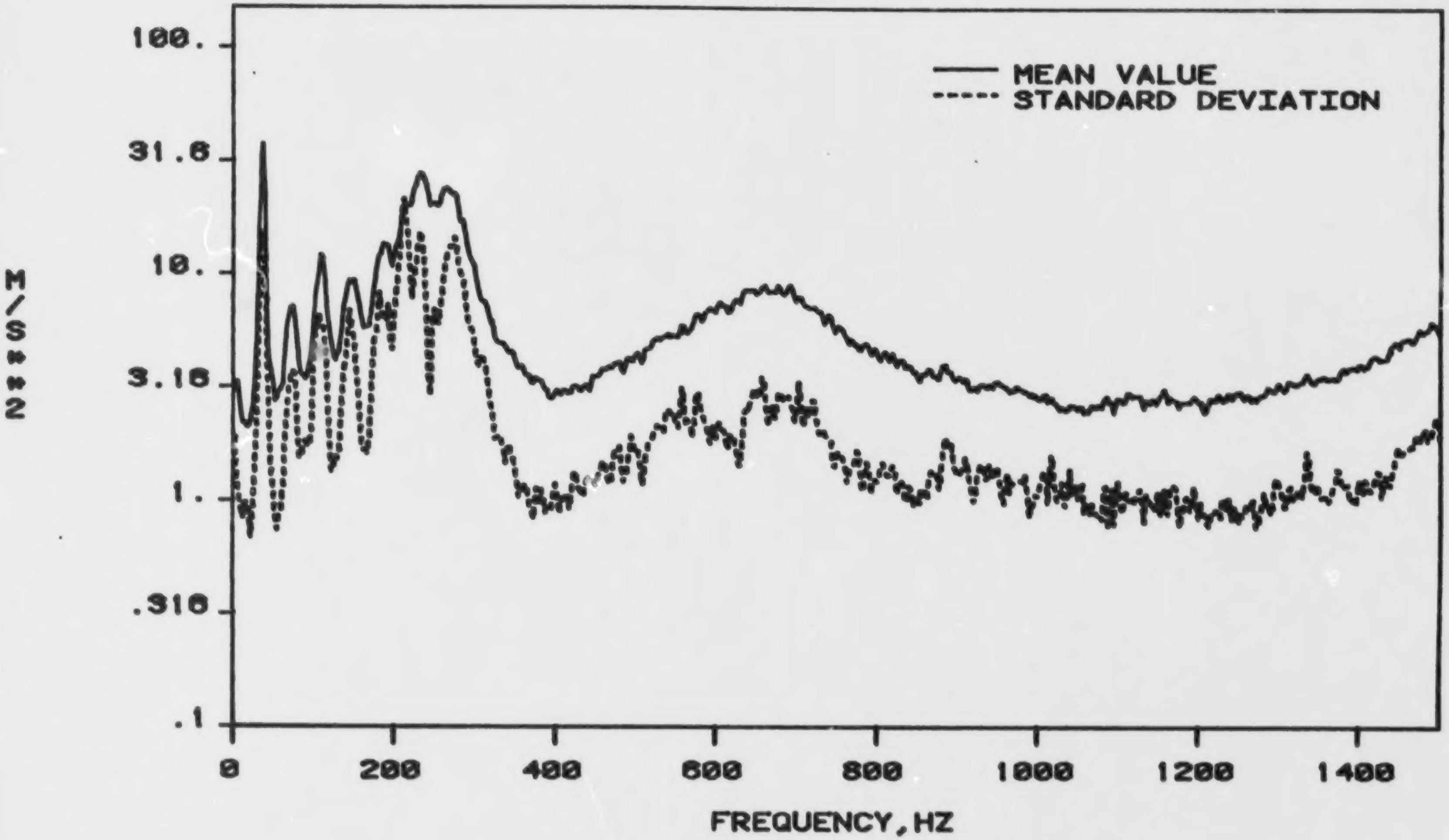


Figure 3.6 R.M.S. ACCELERATION SPECTRA FOR 6 JACK LEG DRILLS USING 8' STEEL (B,12S)

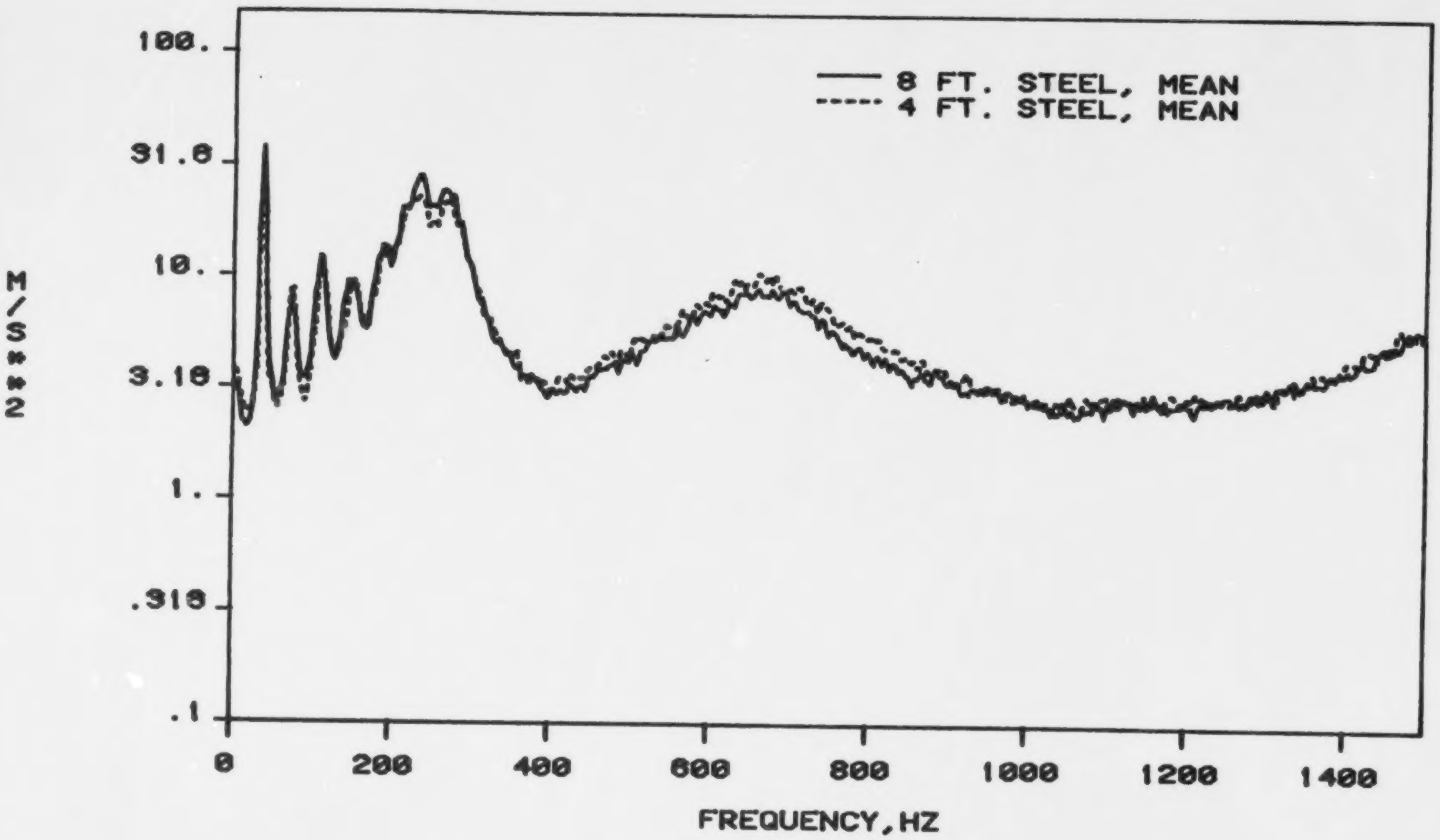


Figure 3.7a COMPARISON OF R.M.S. ACCELERATION SPECTRA FOR JACK LEG DRILLS USING DIFFERENT STEEL LENGTHS (B,6D,12S)

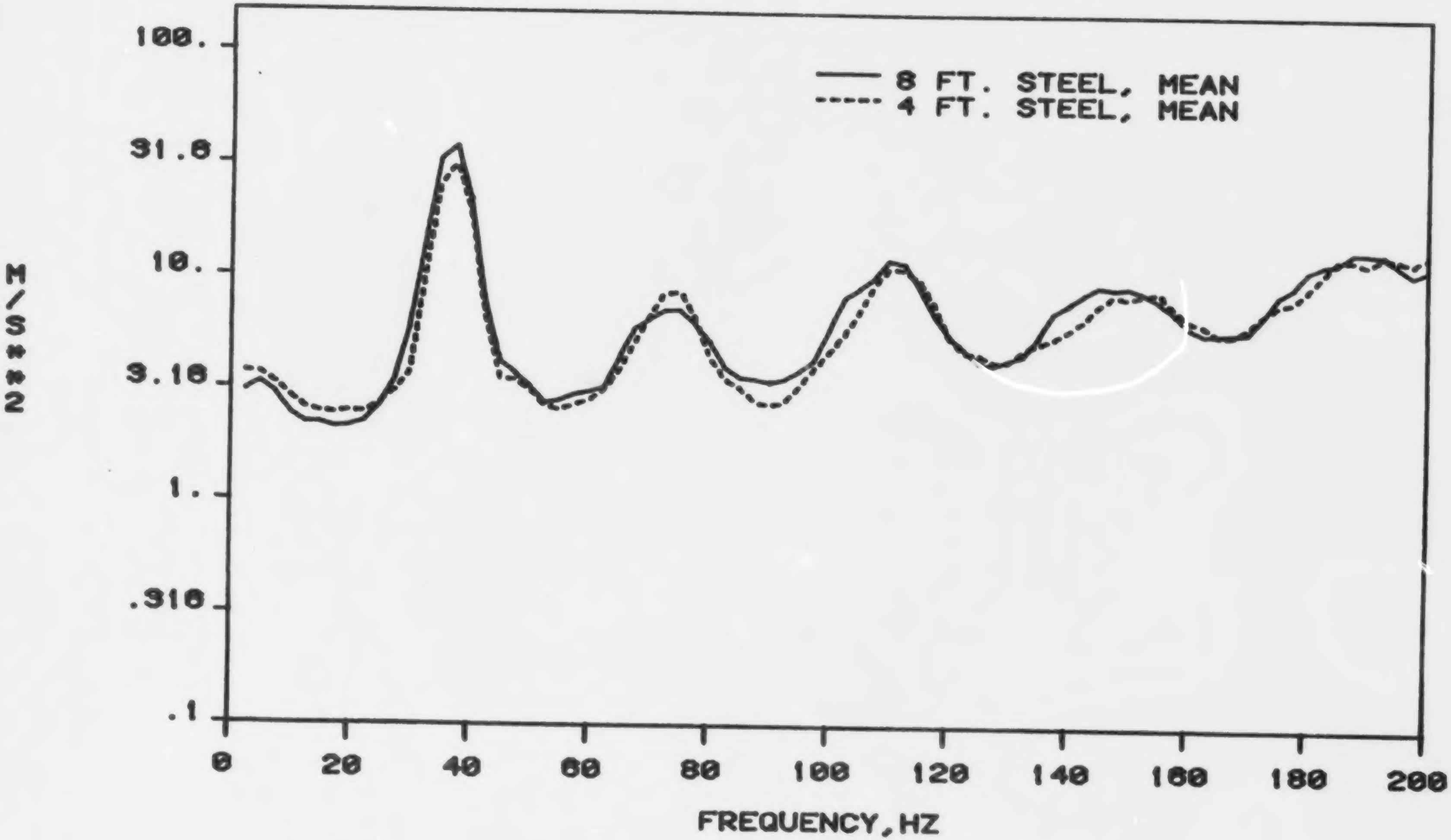


Figure 3.7b COMPARISON OF R.M.S. ACCELERATION SPECTRA FOR JACK LEG DRILLS USING DIFFERENT STEEL LENGTHS (B,6D,12S)

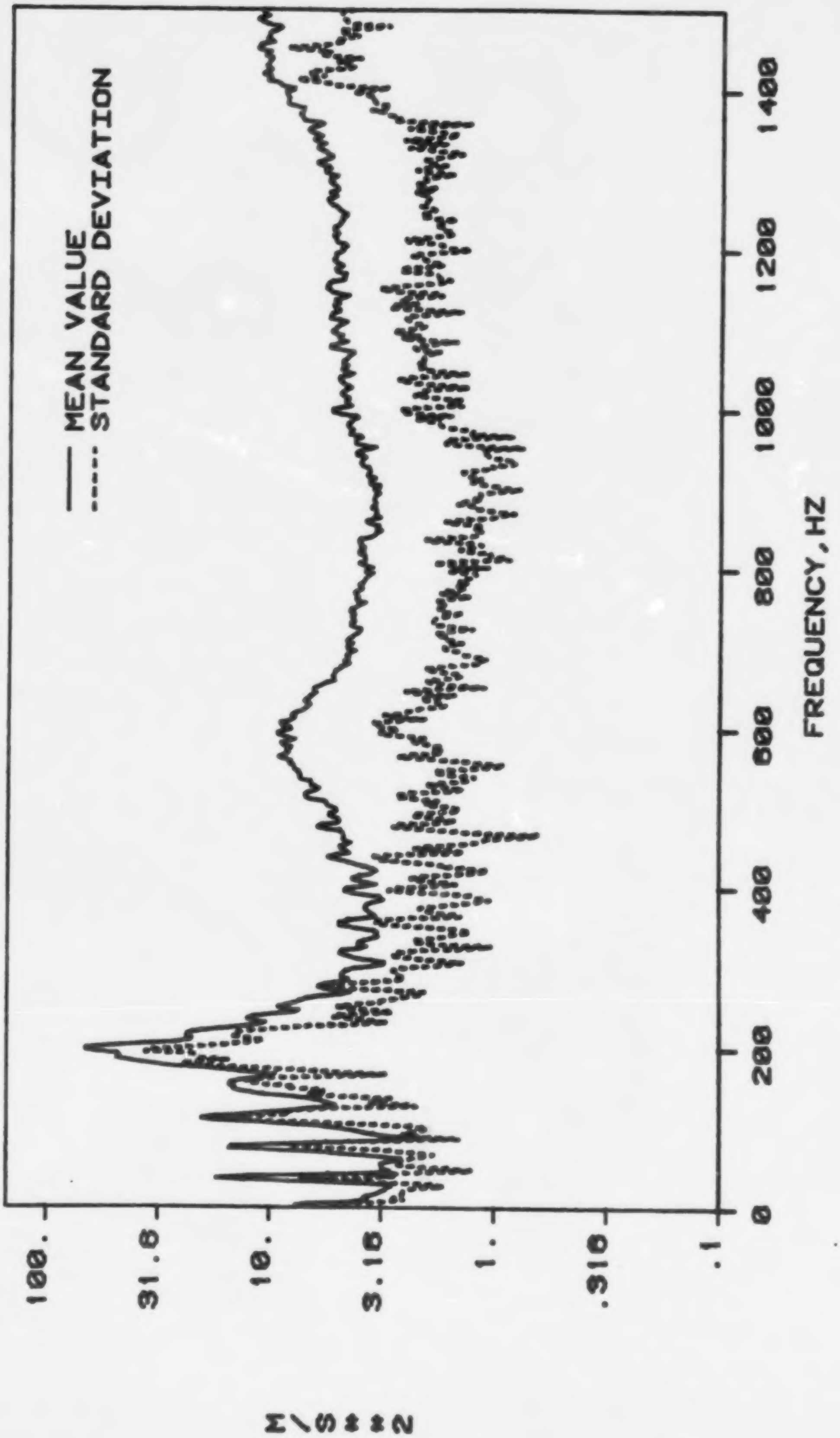


Figure 3.8 R.M.S. ACCELERATION SPECTRA FOR LONG TOM DRILLS (B,2D,7S)

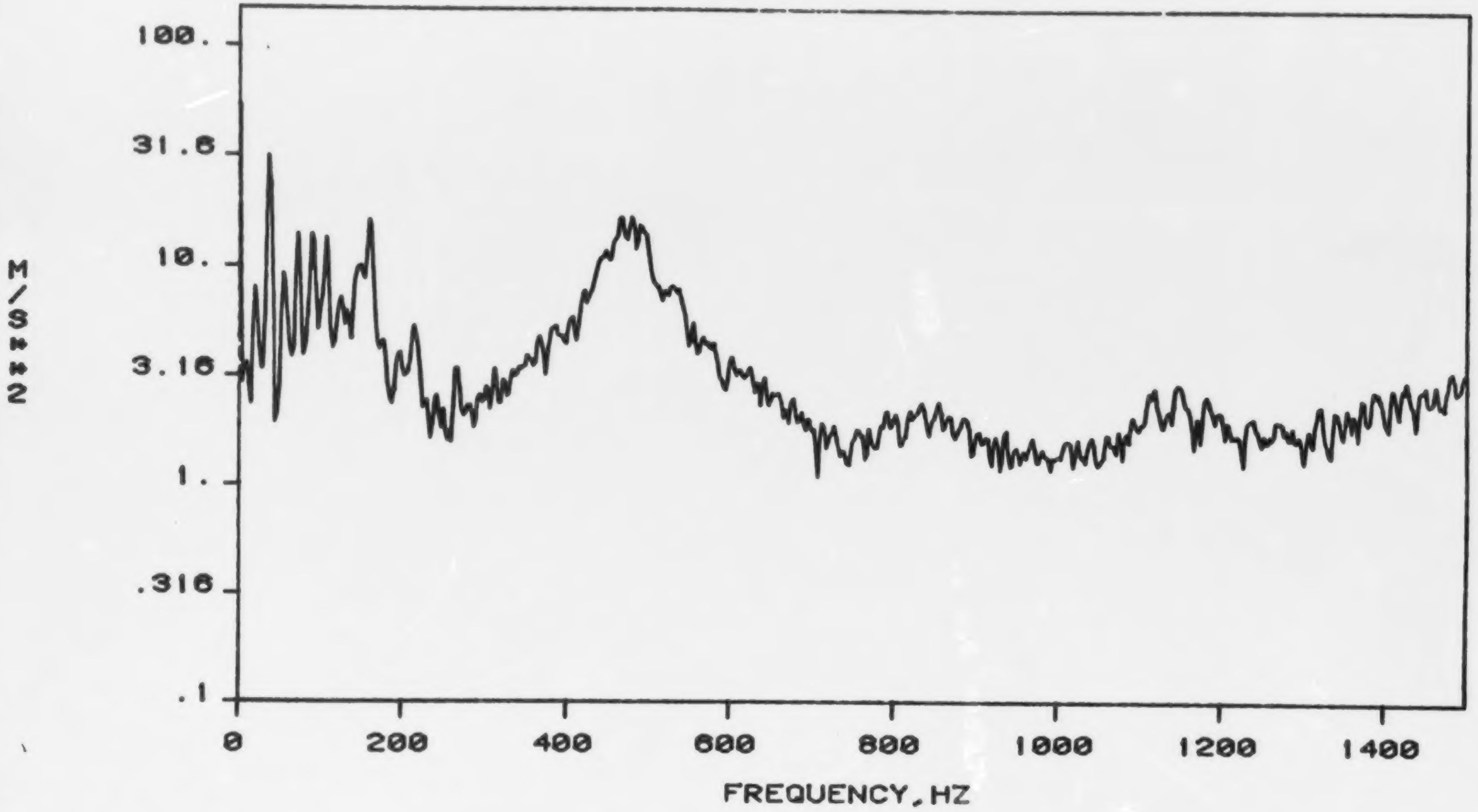


Figure 3.9 R.M.S. ACCELERATION FOR SINGLE STOPER (B,1S)

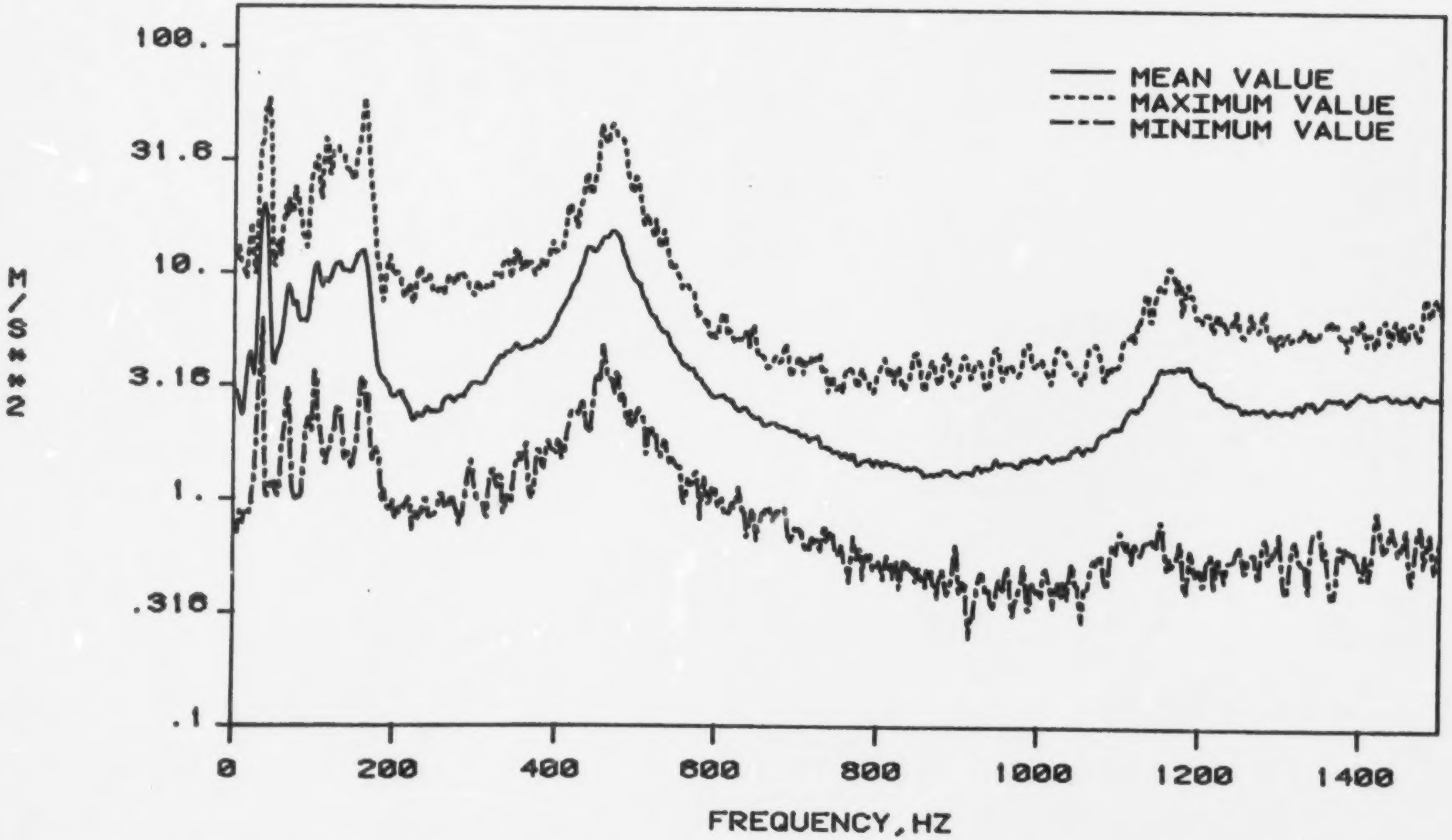


Figure 3.10a R.M.S. ACCELERATION SPECTRA FOR FIVE STOPER DRILLS (B,38S)

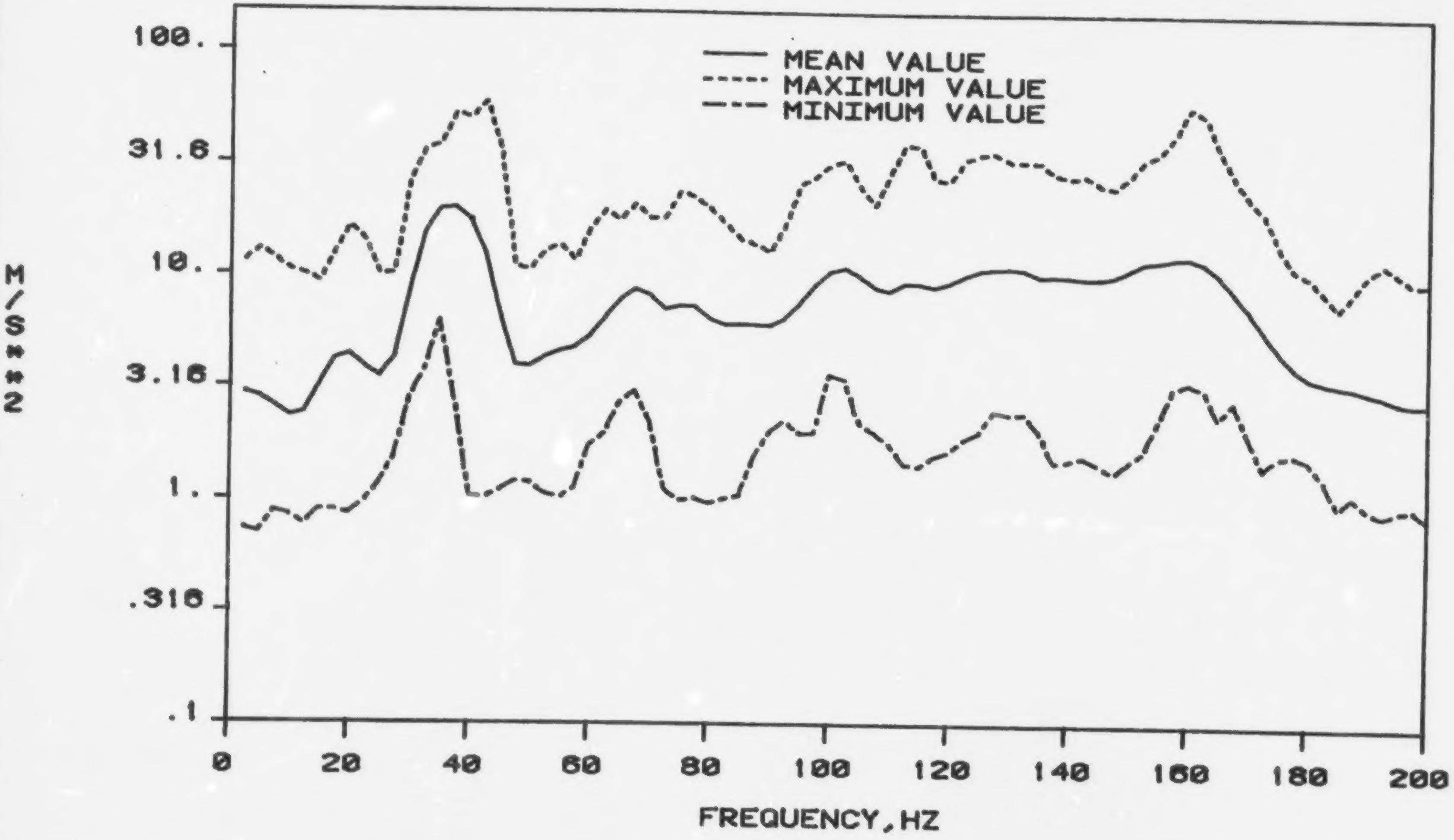


Figure 3.10b R.M.S. ACCELERATION SPECTRA FOR FIVE STOPER DRILLS (B,38S)

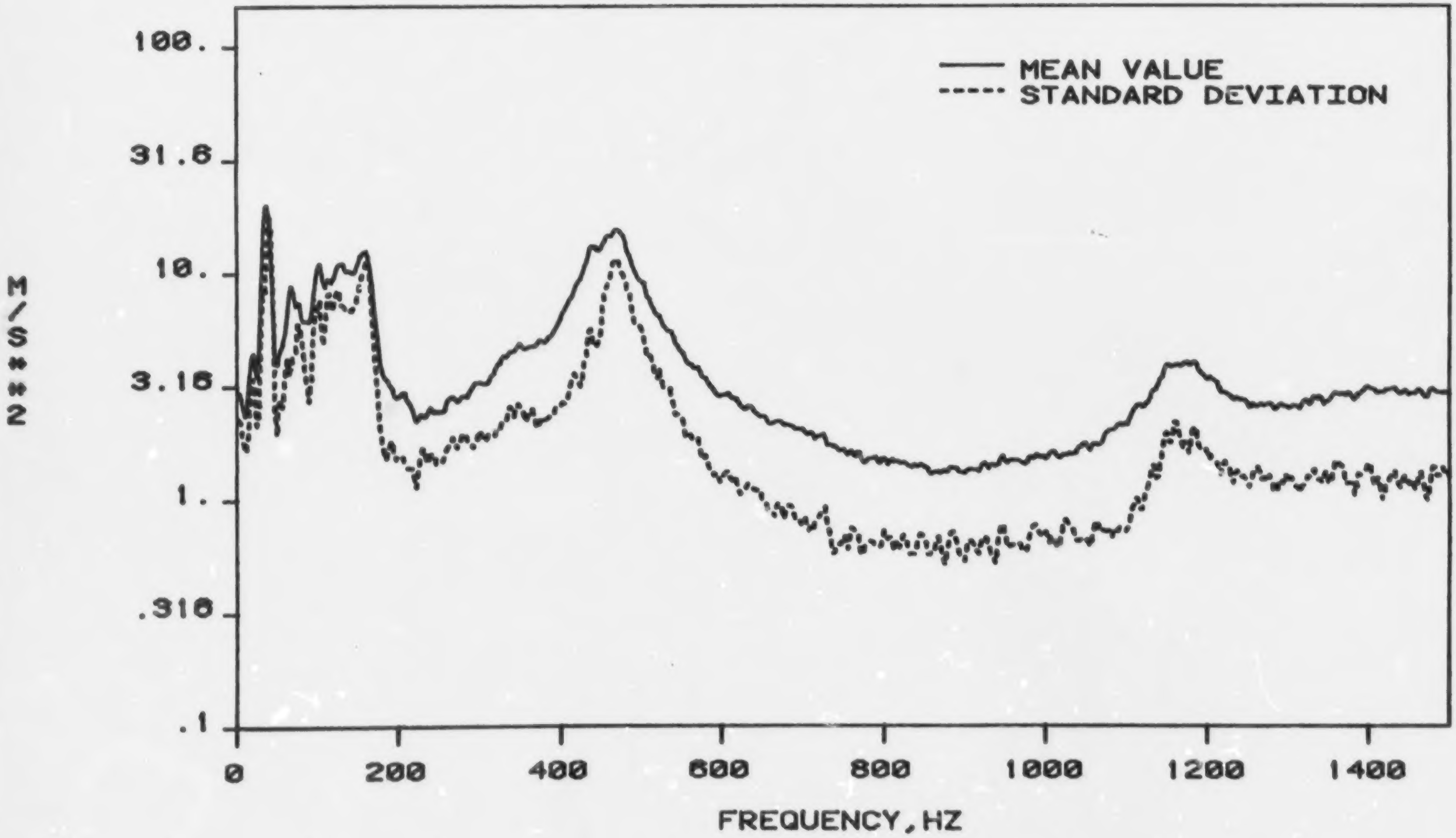


Figure 3.10c R.M.S. ACCELERATION SPECTRA FOR FIVE STOPER DRILLS (B,38S)

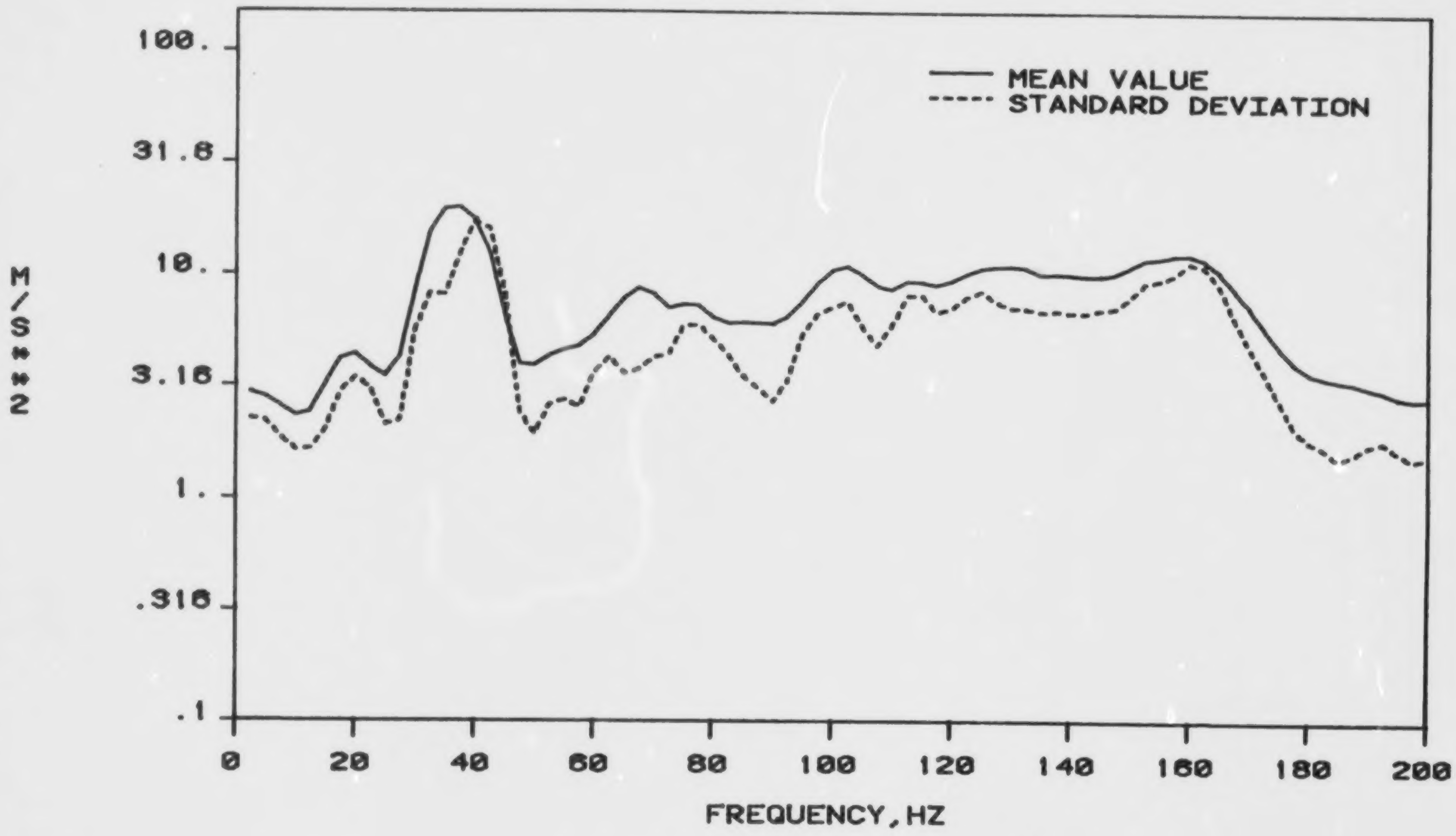


Figure 3.10d R.M.S. ACCELERATION SPECTRA FOR FIVE STOPER DRILLS (B,38S)

drills of the same type are presented. Again the similarity of the individual and mean spectra indicates the existance for stopers of type B of a well defined vibration spectrum signature essentially independent of operating conditions (at least at a given mine site).

Comparing the average spectra for jack legs (Figure 3.3c) and stopers (Figure 3.10c) it may be seen that the acceleration level at the firing frequency for the jack leg drill is approximately 50% higher than for the stoper drill.

During testing of each drill the air pressure to the drill was measured using a needle valve inserted in the hose near the drill. The pressures varied from 75 to 95 psi but no correlation between pressure and vibration level was discernable.

Also during drilling the time taken to drill a particular depth was noted. From these results the average drilling rate for jack leg drills was found to be .56 minutes/foot and for the stoper drills .63 minutes/foot. Then from mine records spanning the period January - July 1982 inclusive the average footage drilled per man shift by the miners at the Westmin mine was found to be:

	Jack Leg Drill	Stoper Drill
Stope miner	48	32
Drift miner	108	28
Raise miner		134

Thus the raise miner would be drilling for at least 134x.63 = 84.4 minutes per man shift. In fact he would be likely drilling for somewhat longer periods as the figures used do not account for the time taken to collar difficult holes and for the time taken in extracting the steel. It would thus appear that a raise miner may be subjected to vibrations for 1.5 hours per man shift. This figure will be used in Section 3.5 in assessing the provisions of ISO DIS 5349. The figure for the drift miner is 78.1 minutes per man shift and thus an overall time of 1.5 hour is not unreasonable for this driller as well. It must also be recognized that the stoper driller is likely to spend much of the drilling time holding the hose, and that with both stopers and jack legs the miner will sometimes release the drill entirely.

3.4 Results of Rock Drill Tests from Kimberley Mine

At the Kimberley mine the stoper drill is more commonly used than the jack leg and at this mine 7 stopers were tested and 10 jack legs. Emphasis was placed upon obtaining jack leg results because of the higher acceleration levels associated with these drills. In this mine two brands of drill are commonly used and thus it was possible to make comparisons between the vibration levels produced by each type of drill.

In Figures 3.11 a-d and 3.12 a-d the results of measurements taken on 4 jack leg drills of type A and 4 jack leg drills of type B respectively are presented. Then in Figures 3.13 a-b a comparison of their mean levels is given. The spectra have distinct forms with drill B having resonant peaks close to 250 and 700 Hz whereas drill A appears to have a resonant peak close to 350 HZ but has higher vibration levels than B above 700 Hz. At the firing frequency, which is somewhat higher for drill B the acceleration levels are practically the same at approximately 30 m/s^2. Comparison of the results presented in Figure 3.13a and those in Figure 3.3c show close agreement between the spectra recorded at the two different mine sites for drill type B.

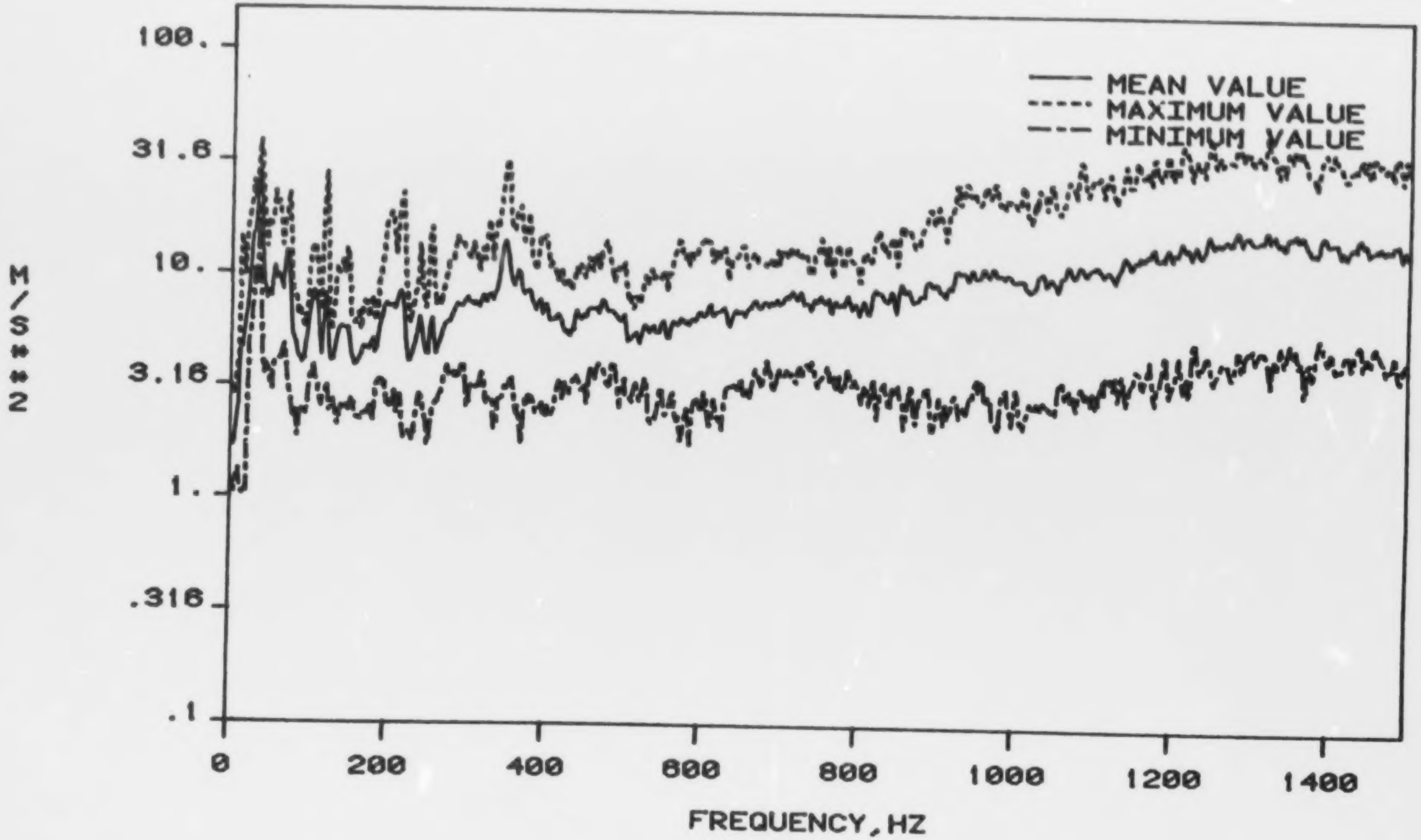


Figure 3.11a R.M.S. ACCELERATION SPECTRA FOR TYPE A JACK LEG DRILL (4D,8S)

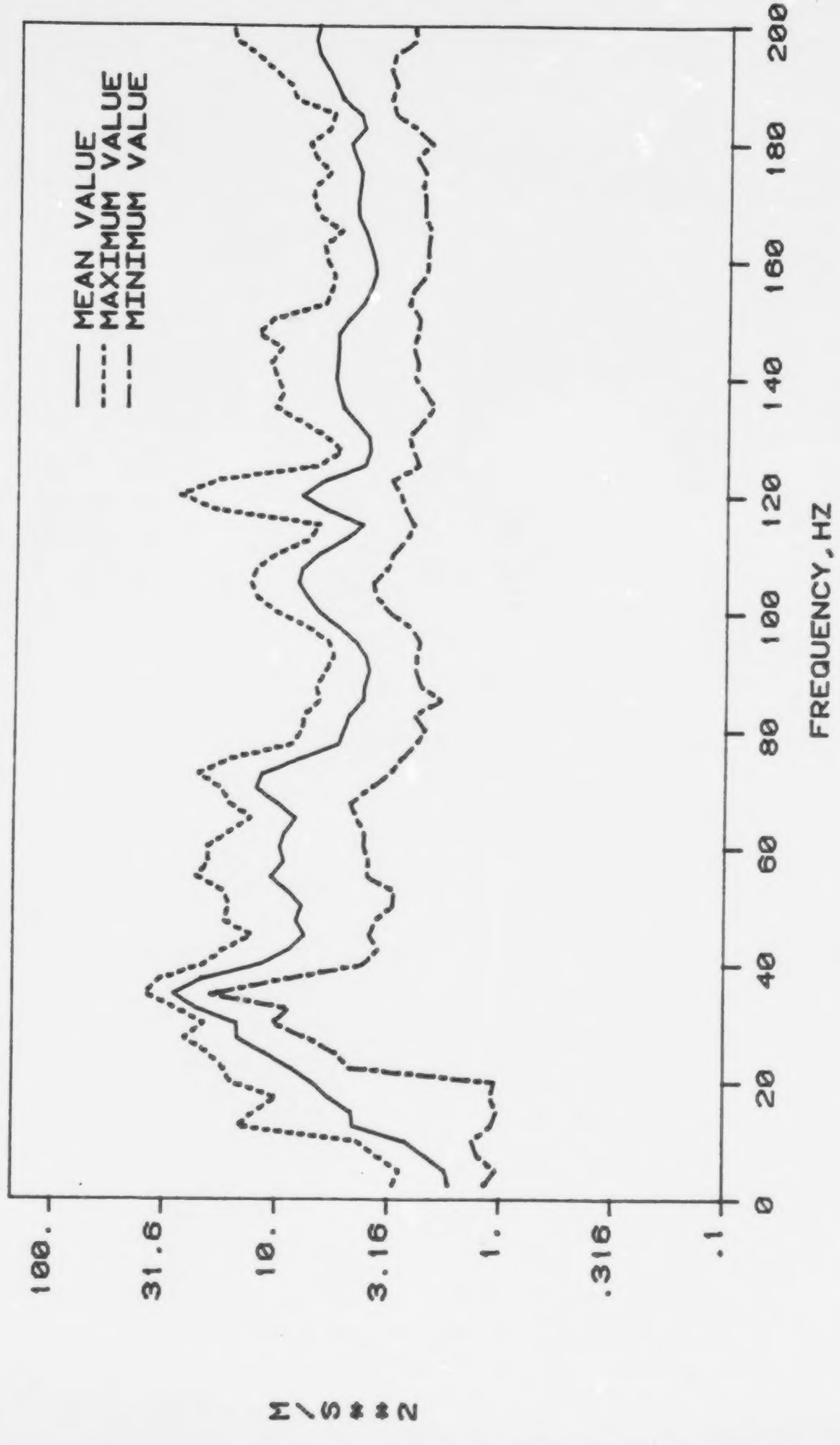


Figure 3.11b R.M.S. ACCELERATION SPECTRA FOR TYPE A JACK LEG DRILL (4D,8S)

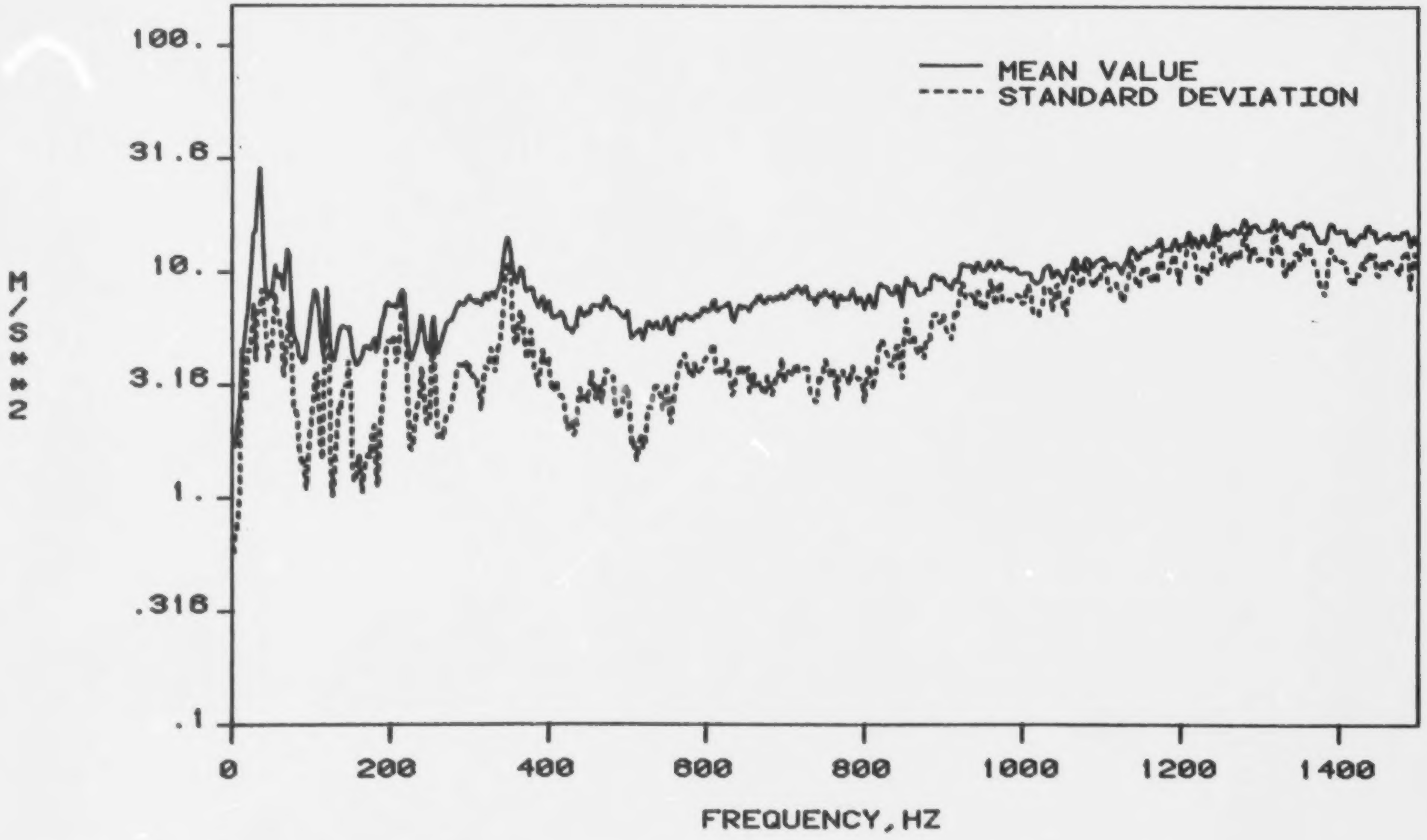


Figure 3.11c R.M.S. ACCELERATION SPECTRA FOR TYPE A JACK LEG DRILL (4D,8S)

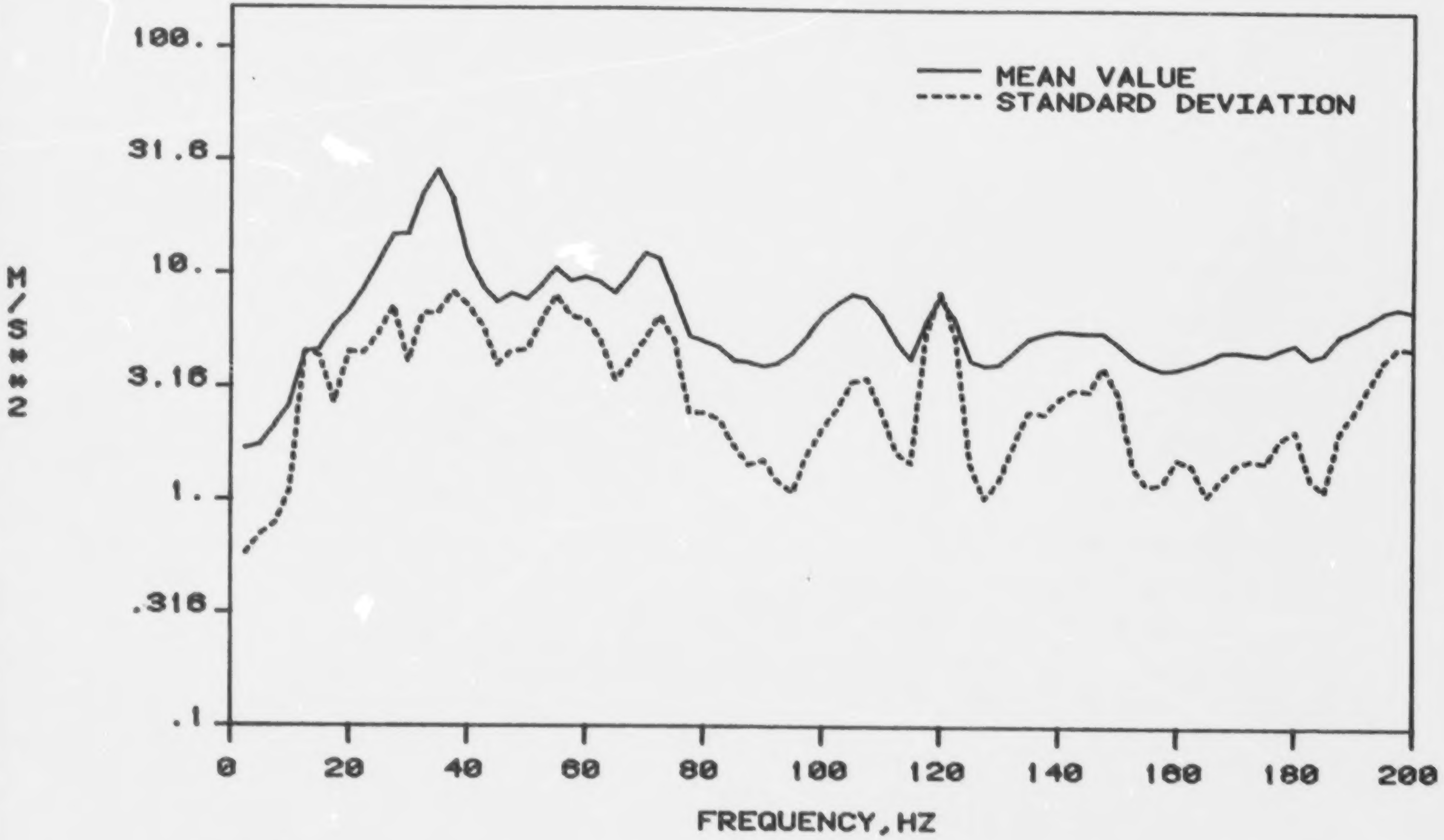


Figure 3.11d R.M.S. ACCELERATION SPECTRA FOR TYPE JACK LEG DRILL (4D,8S)

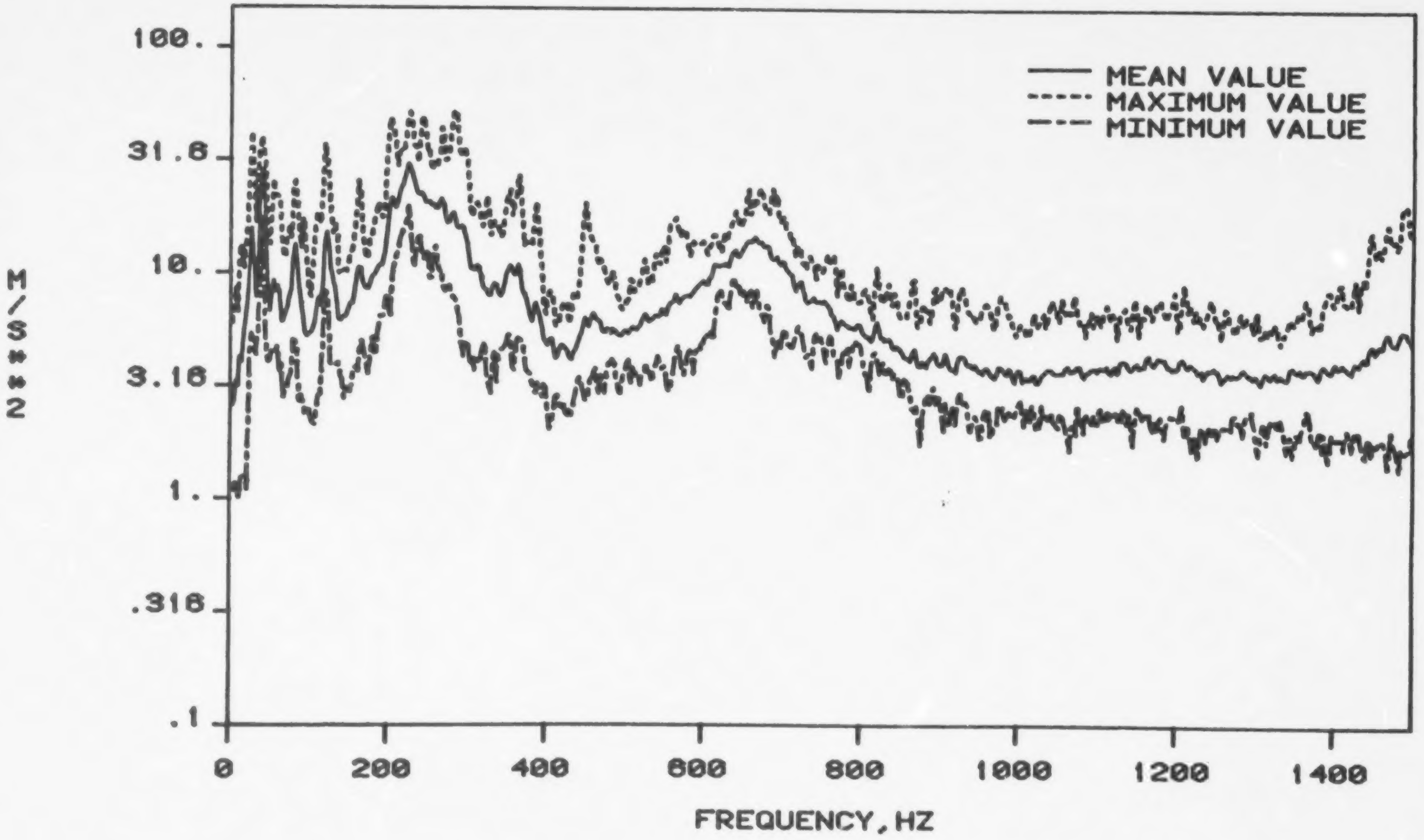


Figure 3.12a R.M.S. ACCELERATION SPECTRA FOR TYPE B JACK LEG DRILL (4D,8S)

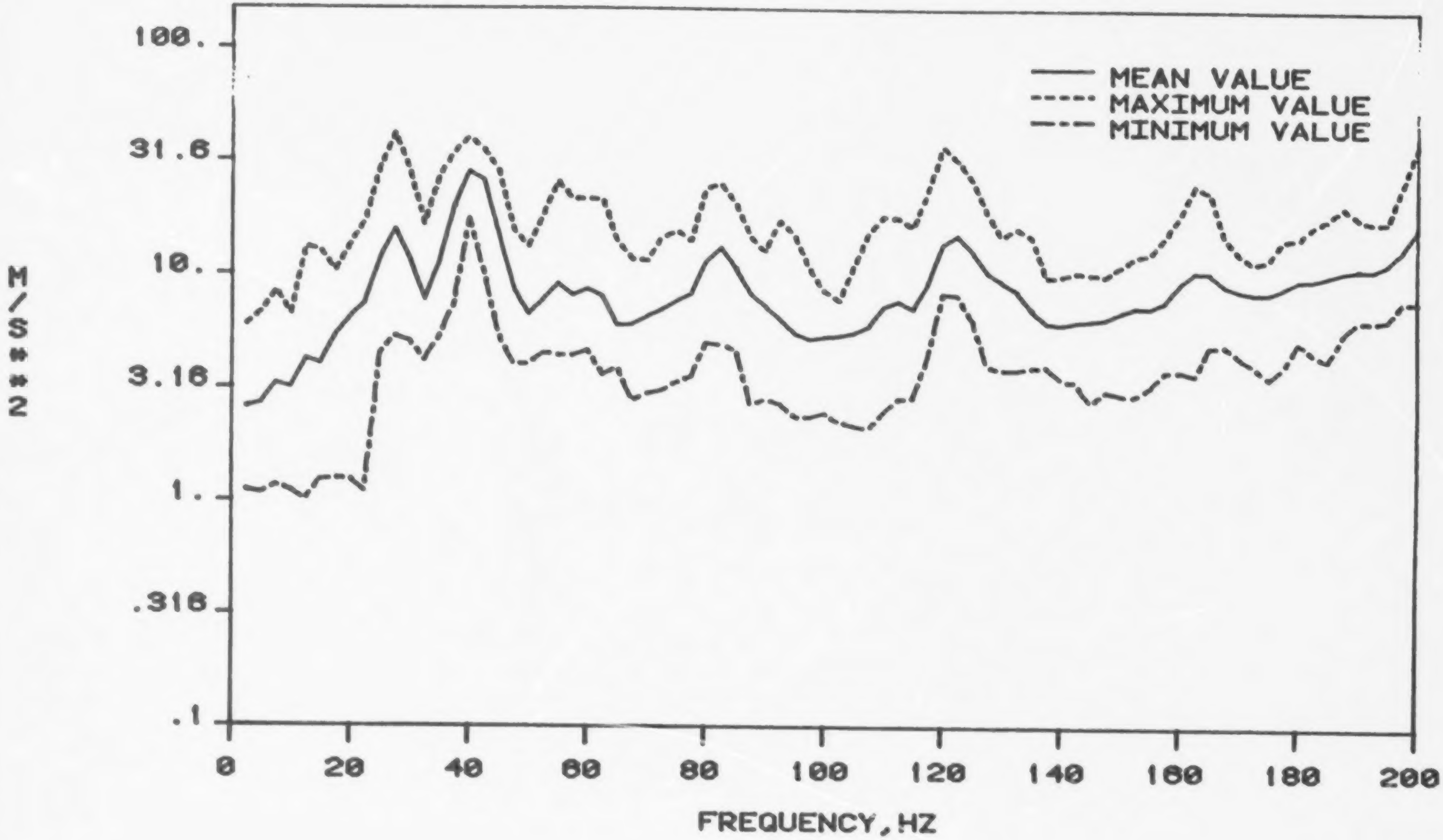


Figure 3.12b R.M.S. ACCELERATION SPECTRA FOR TYPE B JACK LEG DRILL (4D,8S)

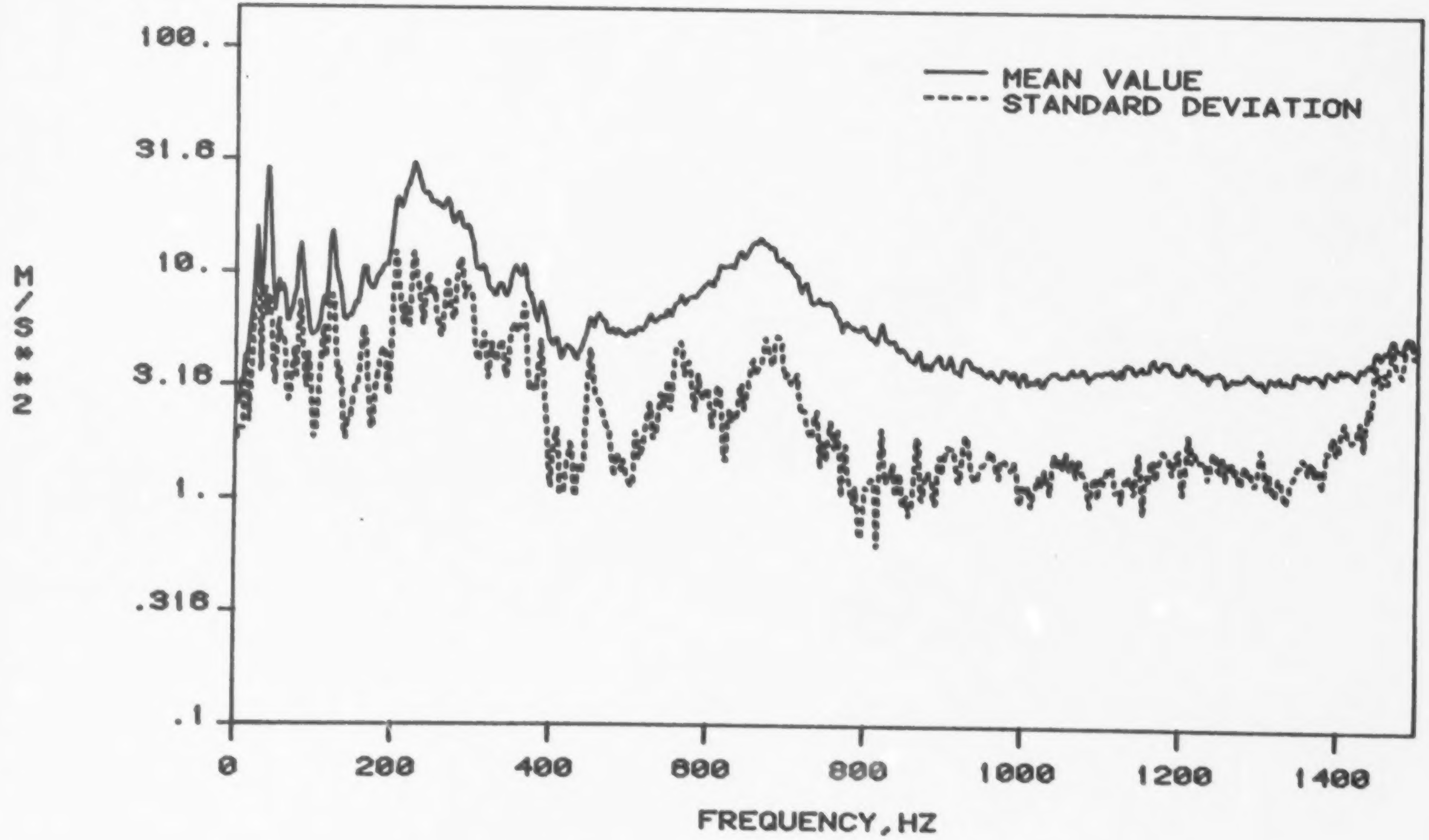


Figure 3.12c R.M.S. ACCELERATION SPECTRA FOR TYPE B JACK LEG DRILL (4D,8S)
]

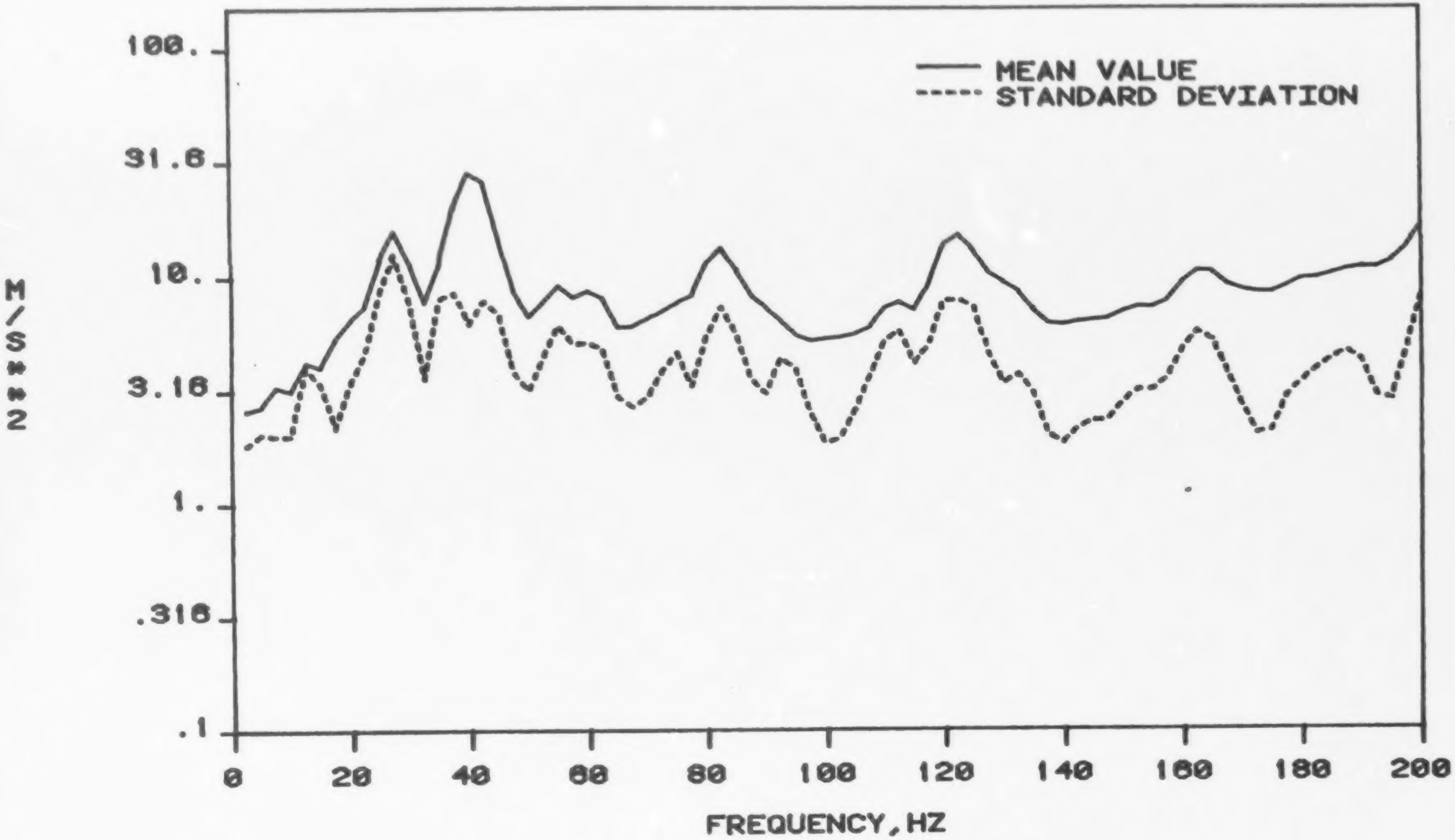


Figure 3.12d R.M.S. ACCELERATION SPECTRA FOR TYPE B JACK LEG DRILL (4D,8S)

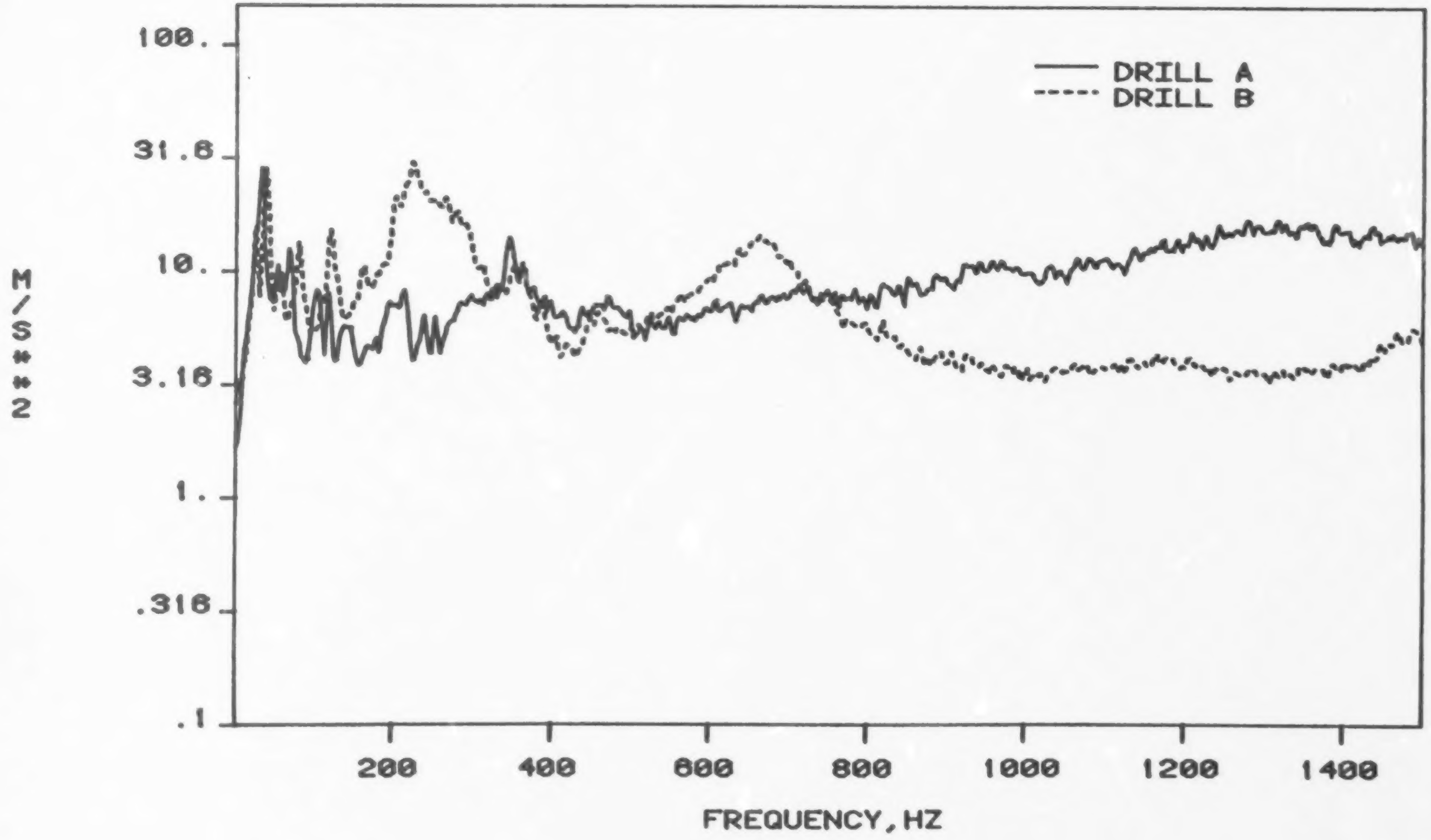


Figure 3.13a COMPARISON OF R.M.S. ACCELERATION SPECTRA BETWEEN JACK LEG DRILLS OF TYPE A AND B (8D,16S)

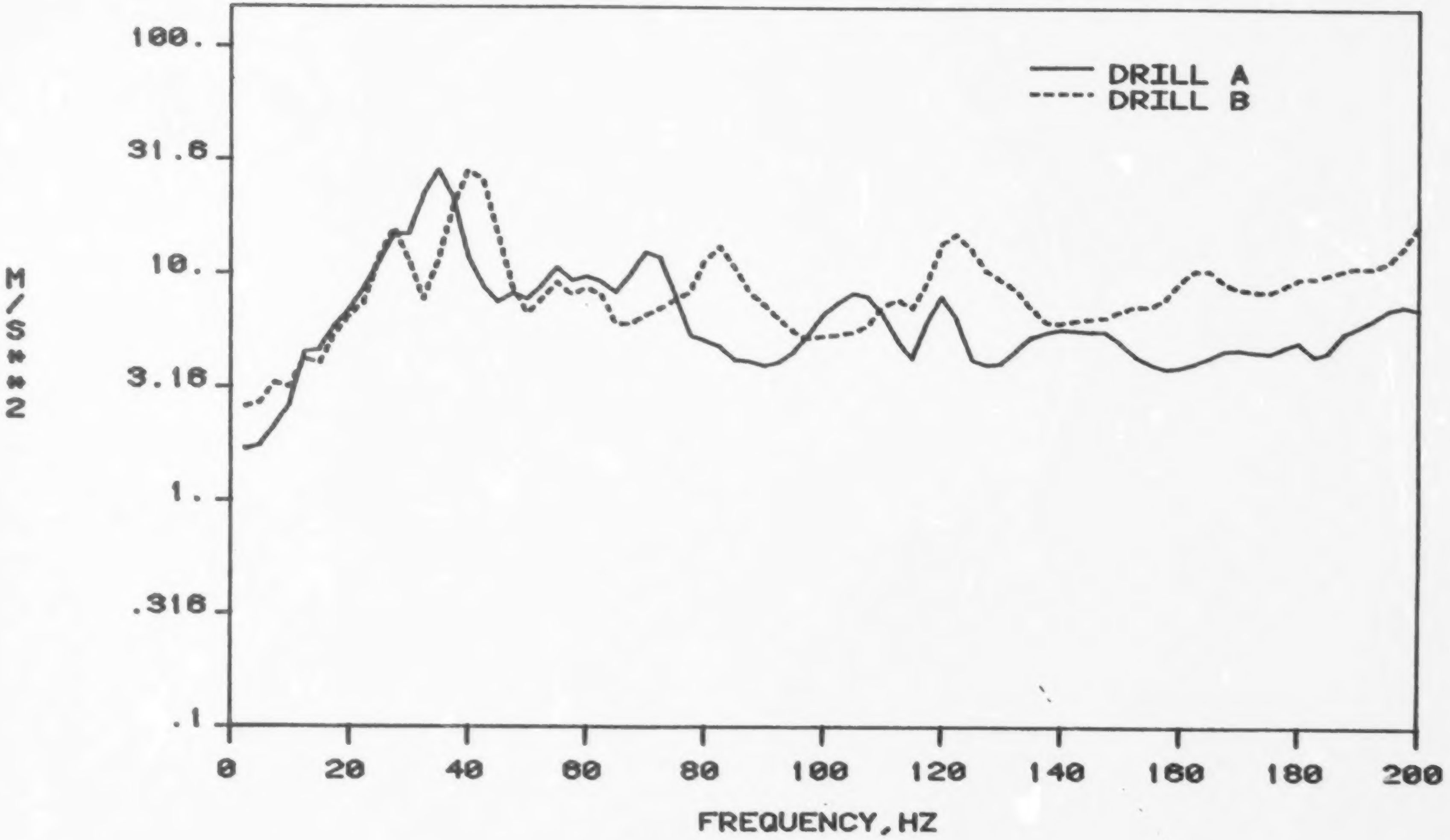


Figure 3.13b COMPARISON OF R.M.S. ACCELRATION SPECTRA BETWEEN JACK LEG DRILLS OF TYPE A AND B (4D,8S)

Individual samples of two other types of jack leg (not commonly used in the mine) were also obtained. These results are displayed in Figure 3.14. Note however that such spectrum represents only one sample.

With stopers, drilling is often performed from a timber platform, either built up from the ground, or attached to the walls of a raise. Such a support system is of course less rigid than that used when drilling from a rock base, and the possibility arises that the flexibility (dynamic characteristic) of the timber supports may affect the level of vibration. To this end Figures 3.15 a-d and 3.16 a-d present the results of tests for stoper drills with timber and rock supports respectively. In both cases the drills used were of type A. In Figure 3.17 a comparison is presented that illustrates the effect of the support condition. As may be seen in the range up to 500 Hz, although the shape of the spectrum is the same, the vibration levels associated with the timber supported drills are significantly lower.

In practise when drilling with a stoper the miner may hold the hose rather than the drill handle after the hole has been collared. Figures 3.18 a-d present the results of acceleration levels recorded on the hose in directions at right angles to the centre line of the hose. The results indicate peaks at the firing frequency and at approximately 200 Hz with peak level at the firing frequency of the same magnitude as the timber supported stoper, but at higher frequencies the levels are much reduced.

The effect of steel length on the vibration level of stopers was, as in the case of jack leg drills, not found to be significant. Figures 3.19 a-b present a representative comparison of the results

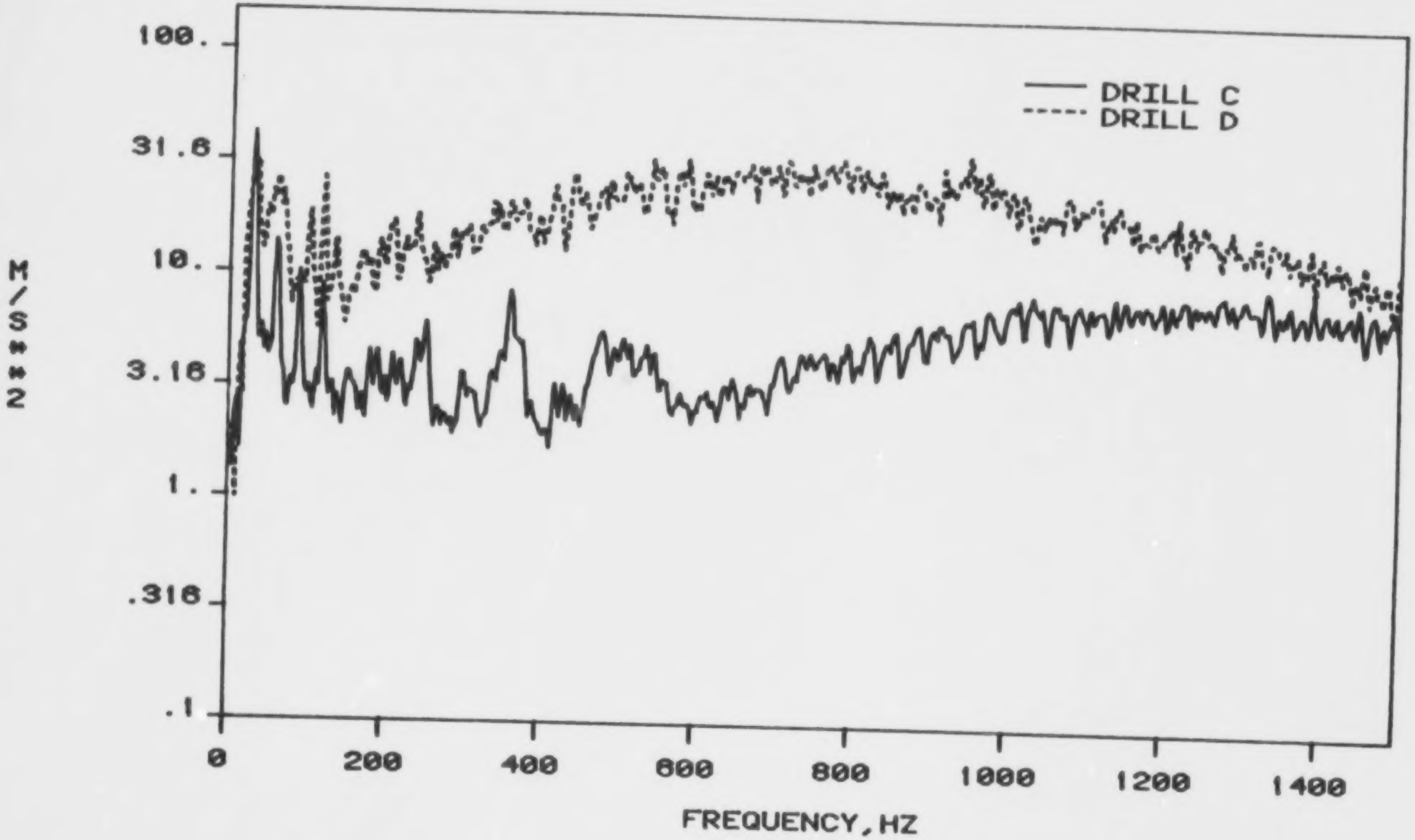


Figure 3.14 COMPARISON OF R.M.S. ACCELERATION SPECTRA BETWEEN JACK LEG DRILLS OF TYPE C AND D (2D,2S)

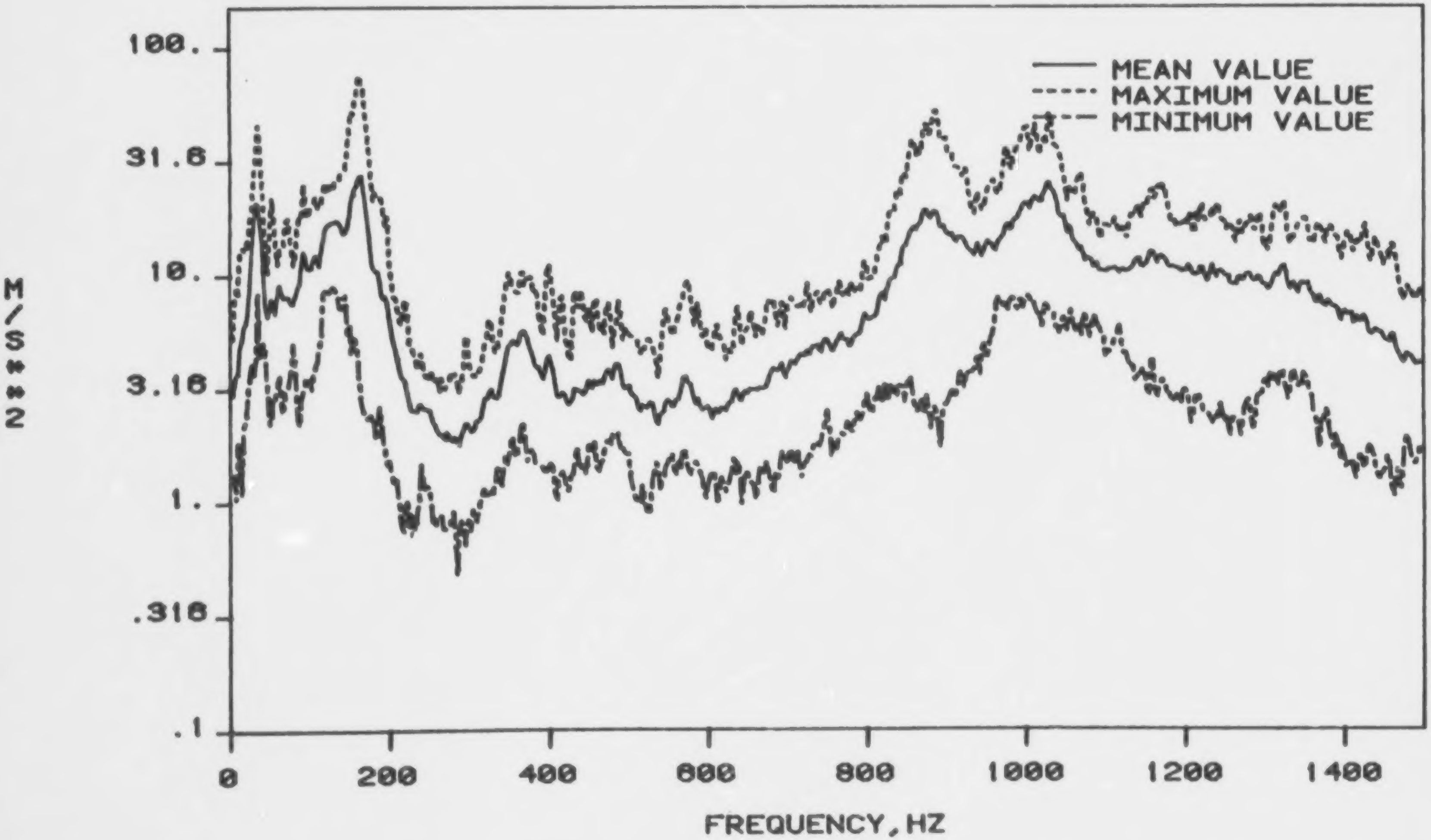


Figure 3.15a R.M.S. ACCELERATION RECORDS FOR TIMBER SUPPORTED STOPER DRILLS (A,3D,10S)

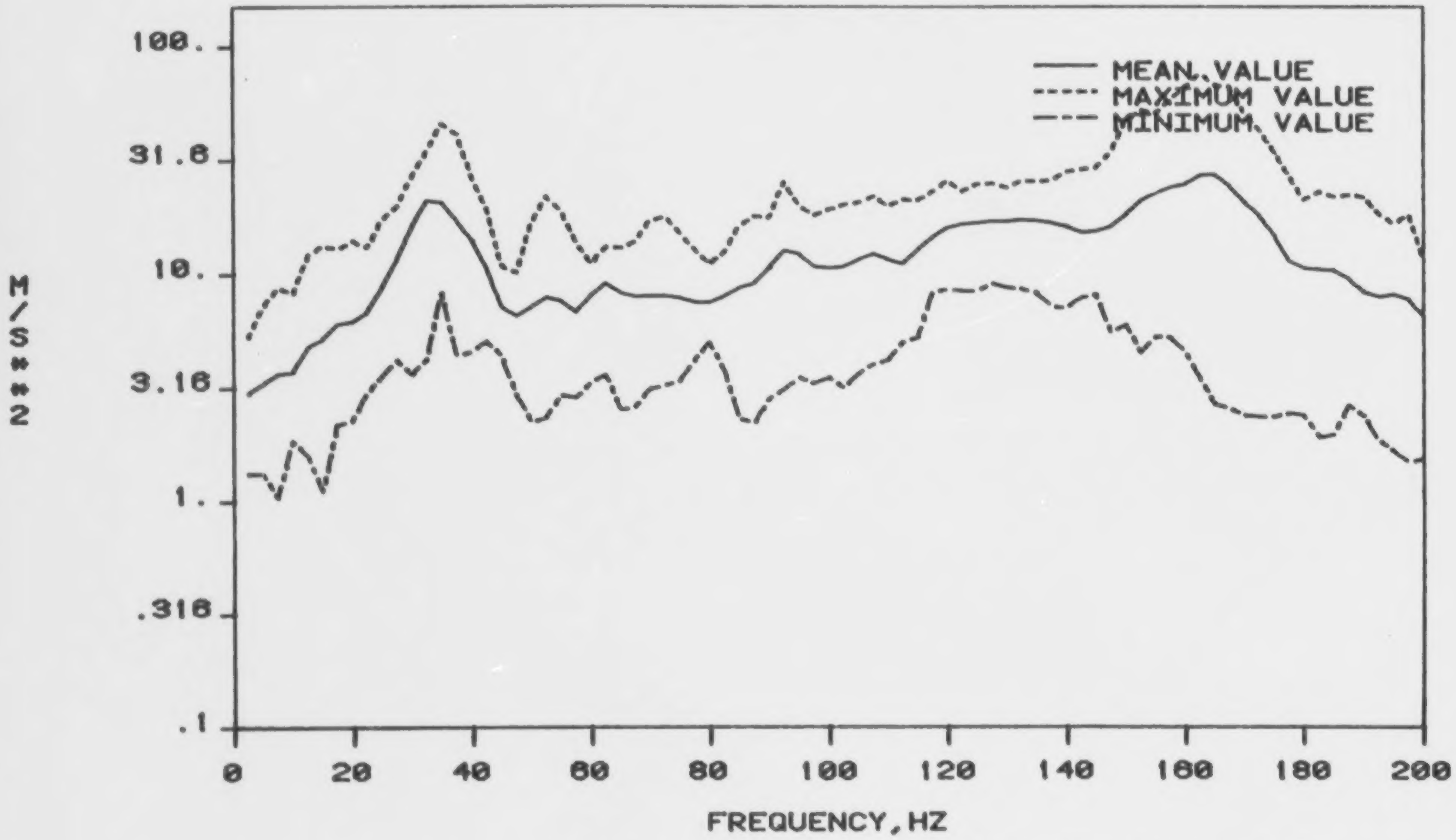


Figure 3.15b R.M.S. ACCELERATION RECORDS FOR TIMBER SUPPORTED STOPER DRILLS (A,3D,10S)

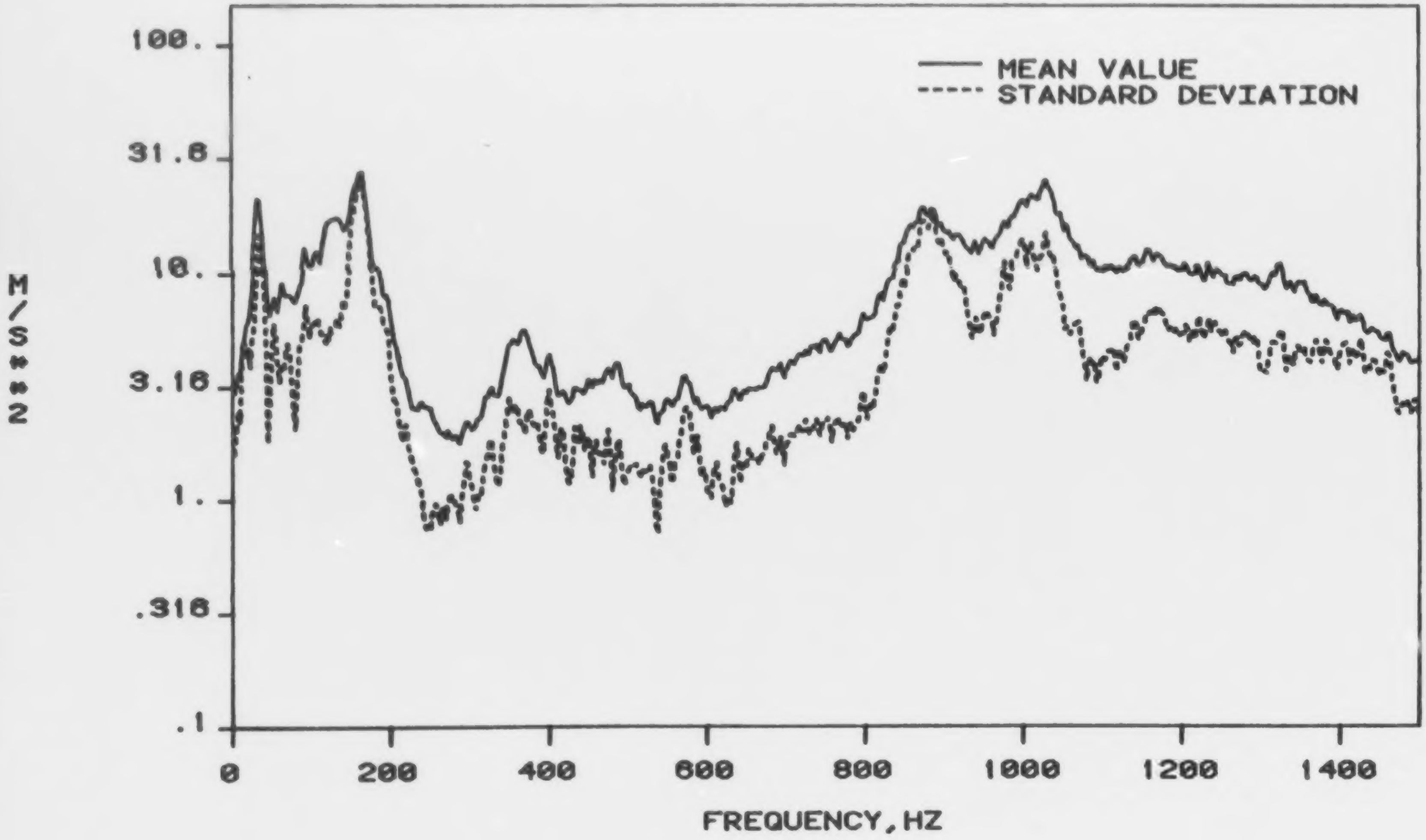


Figure 3.15c R.M.S. ACCELERATION RECORDS FOR TIMBER SUPPORTED STOPER DRILLS (A,3D,10S)

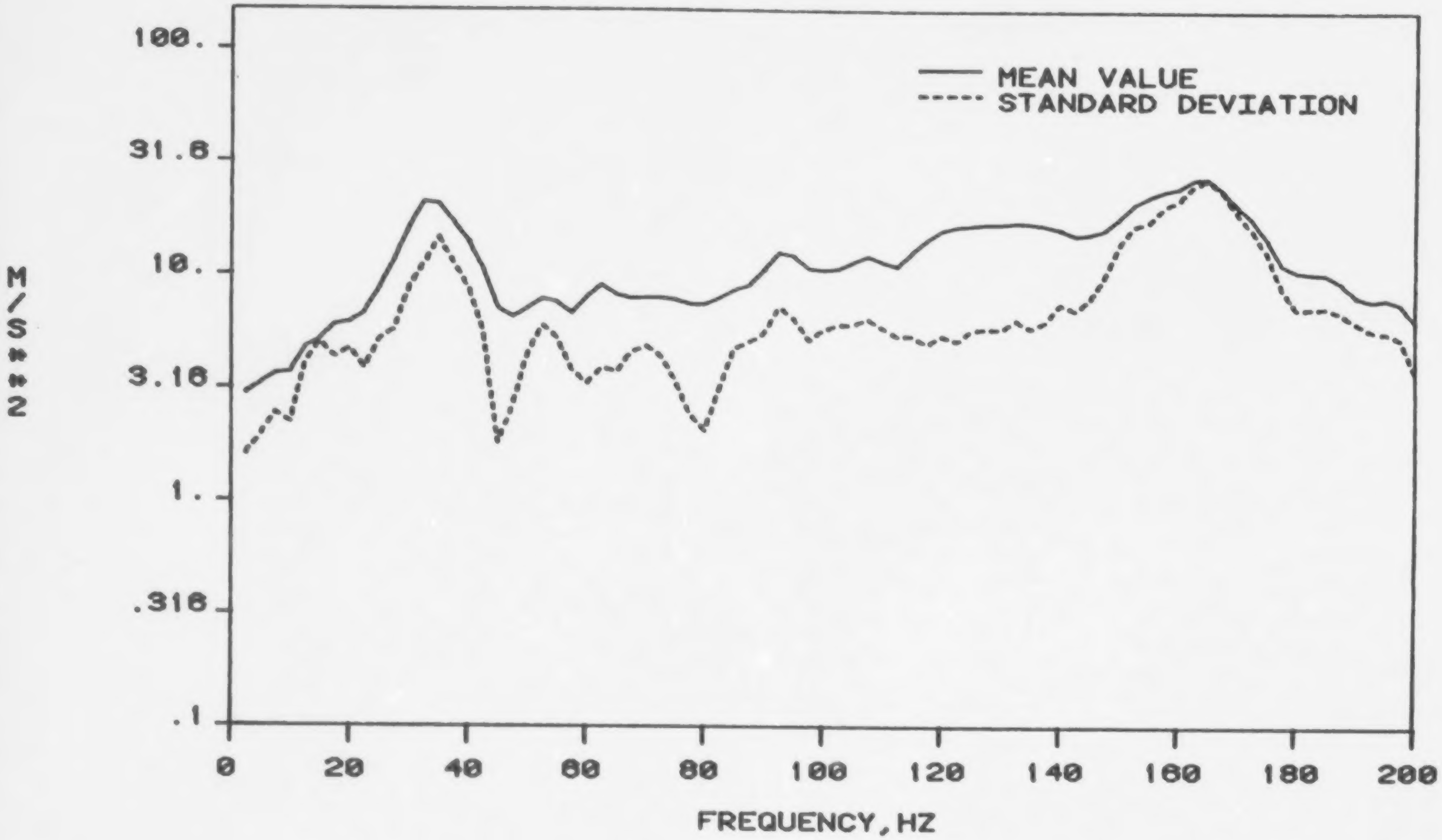


Figure 3.15d R.M.S. ACCELERATION RECORDS FOR TIMBER SUPPORTED STOPER DRILLS(A,3D,10S)

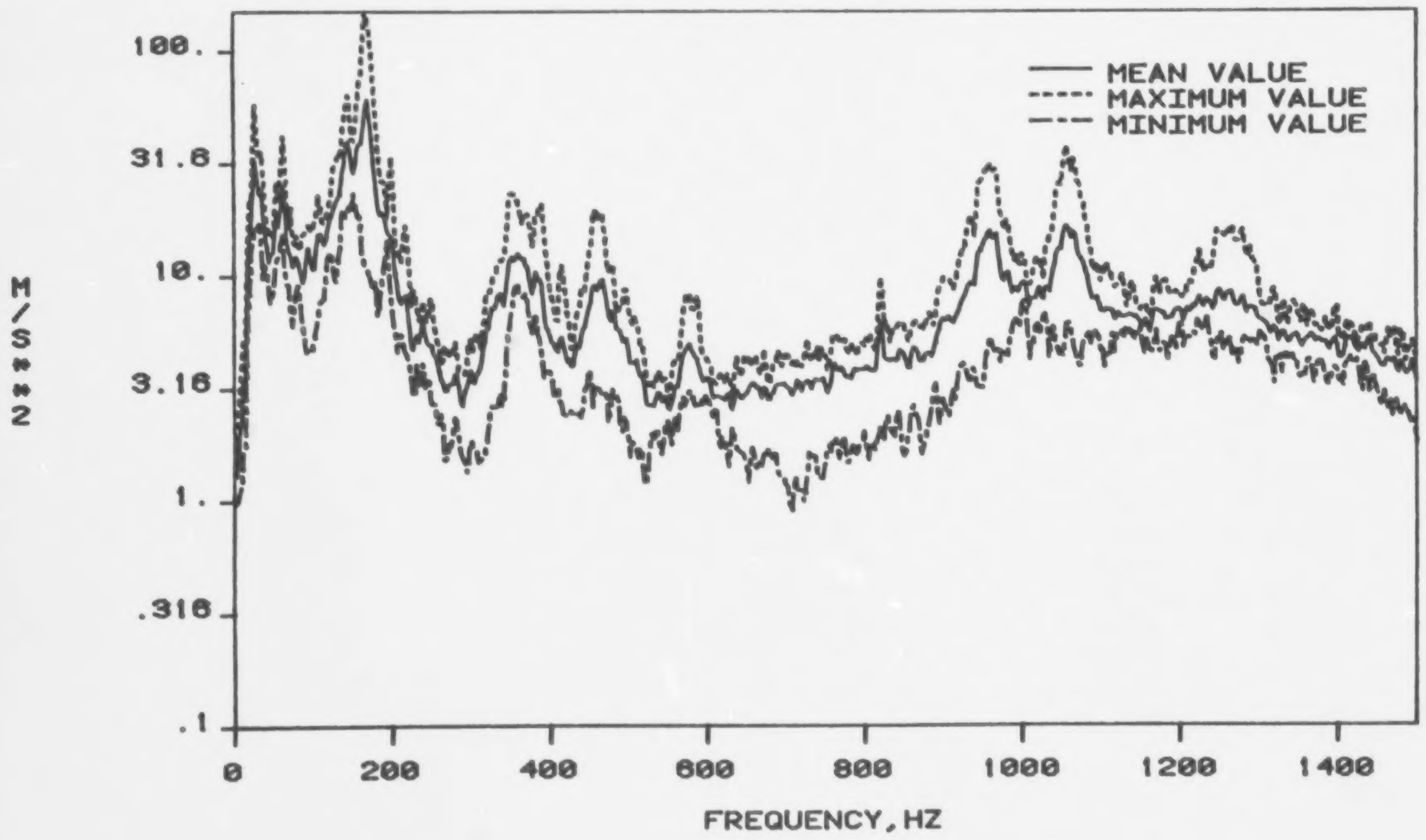


Figure 3.16a R.M.S. ACCELERATION SPECTRA FOR ROCK SUPPORTED STOPER DRILLS (A,2D,5S)

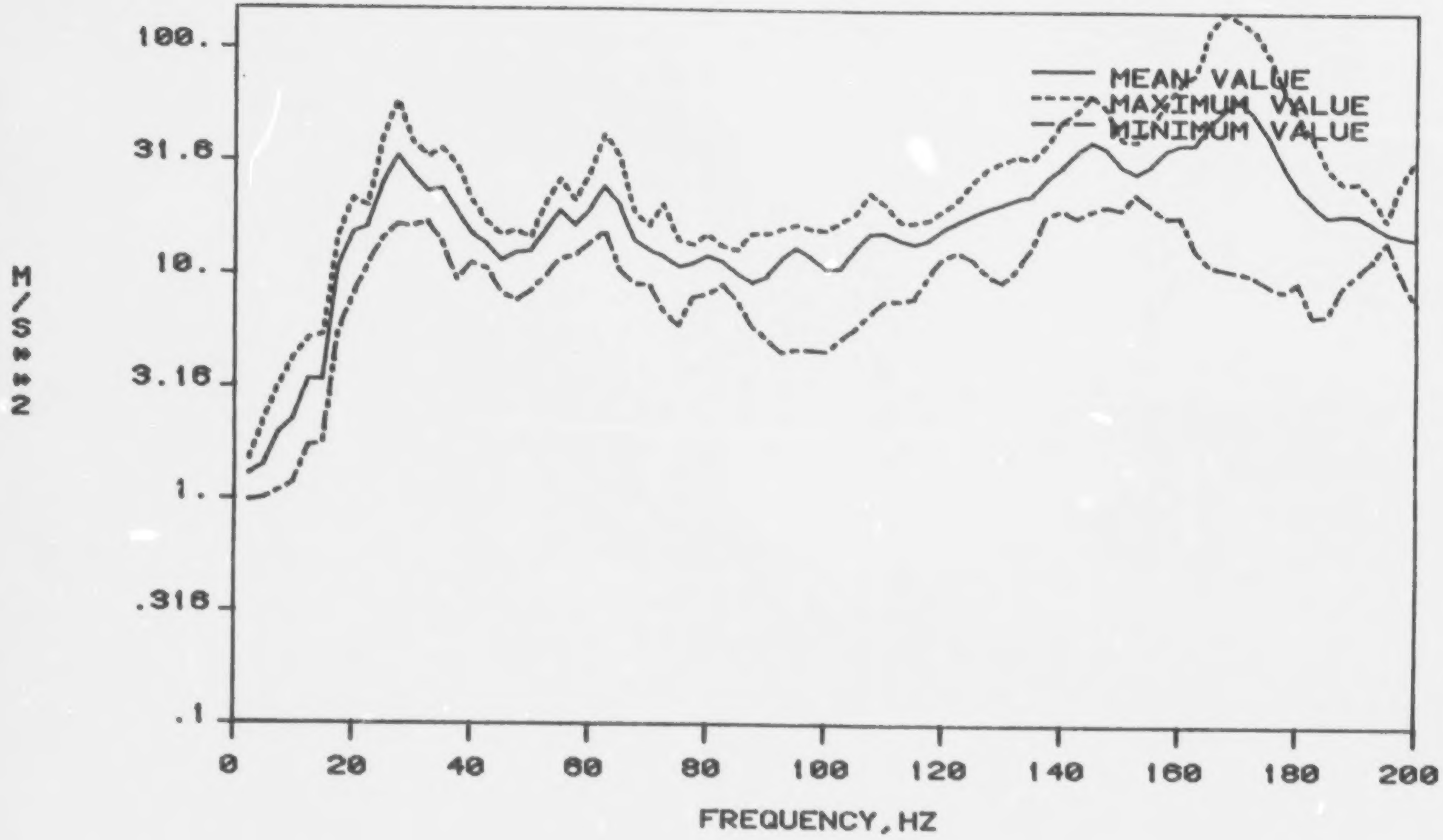


Figure 3.16b R.M.S. ACCELERATION SPECTRA FOR ROCK SUPPORTED STOPER DRILLS (A,2D,5S)

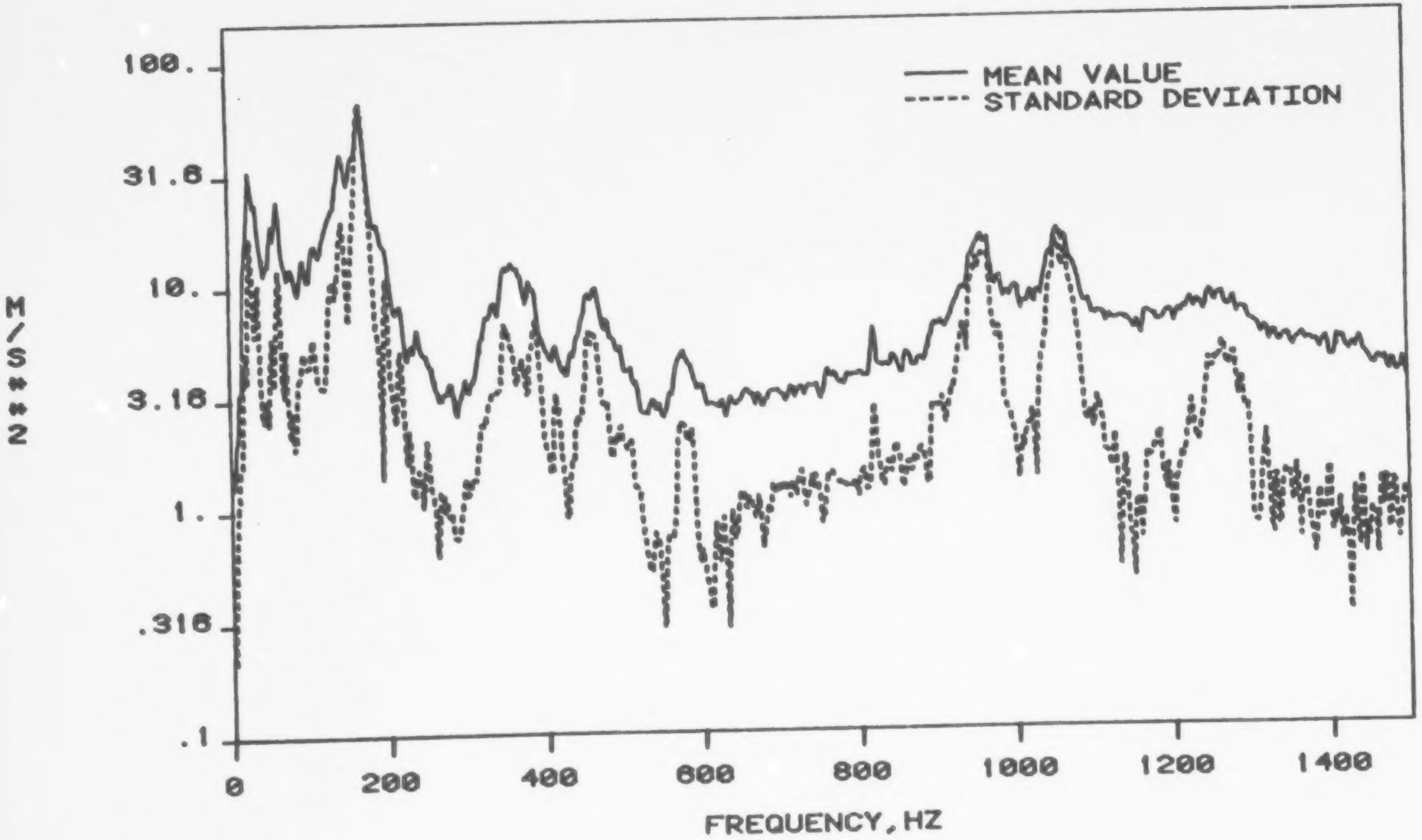


Figure 3.16c R.M.S. ACCELERATION SPECTRA FOR ROCK SUPPORTED STOPER DRILLS (A,2D,5S)

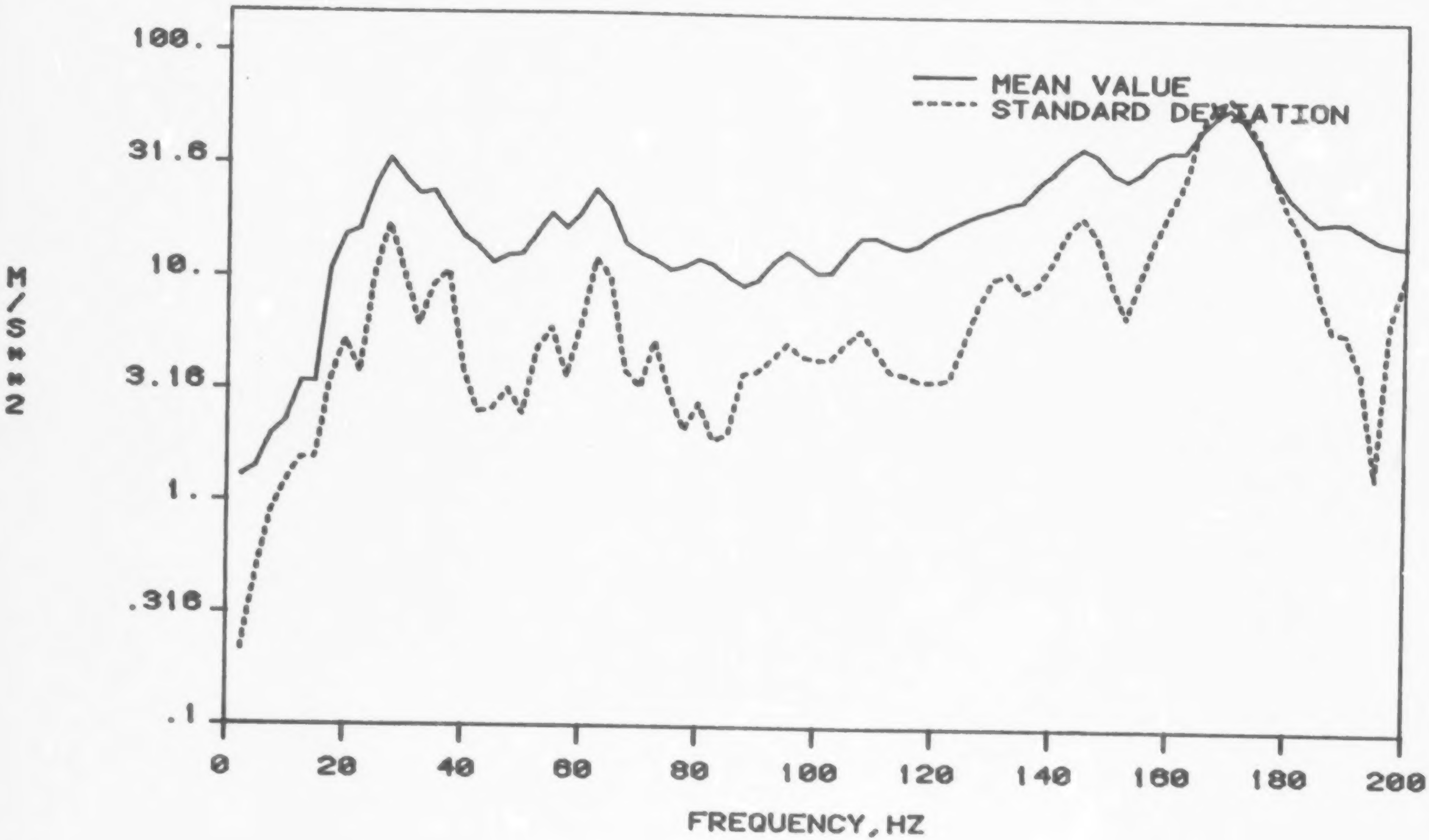


Figure 3.16d R.M.S. ACCELERATION SPECTRA FOR ROCK SUPPORTED STOPER DRILLS (A,2D,5S)

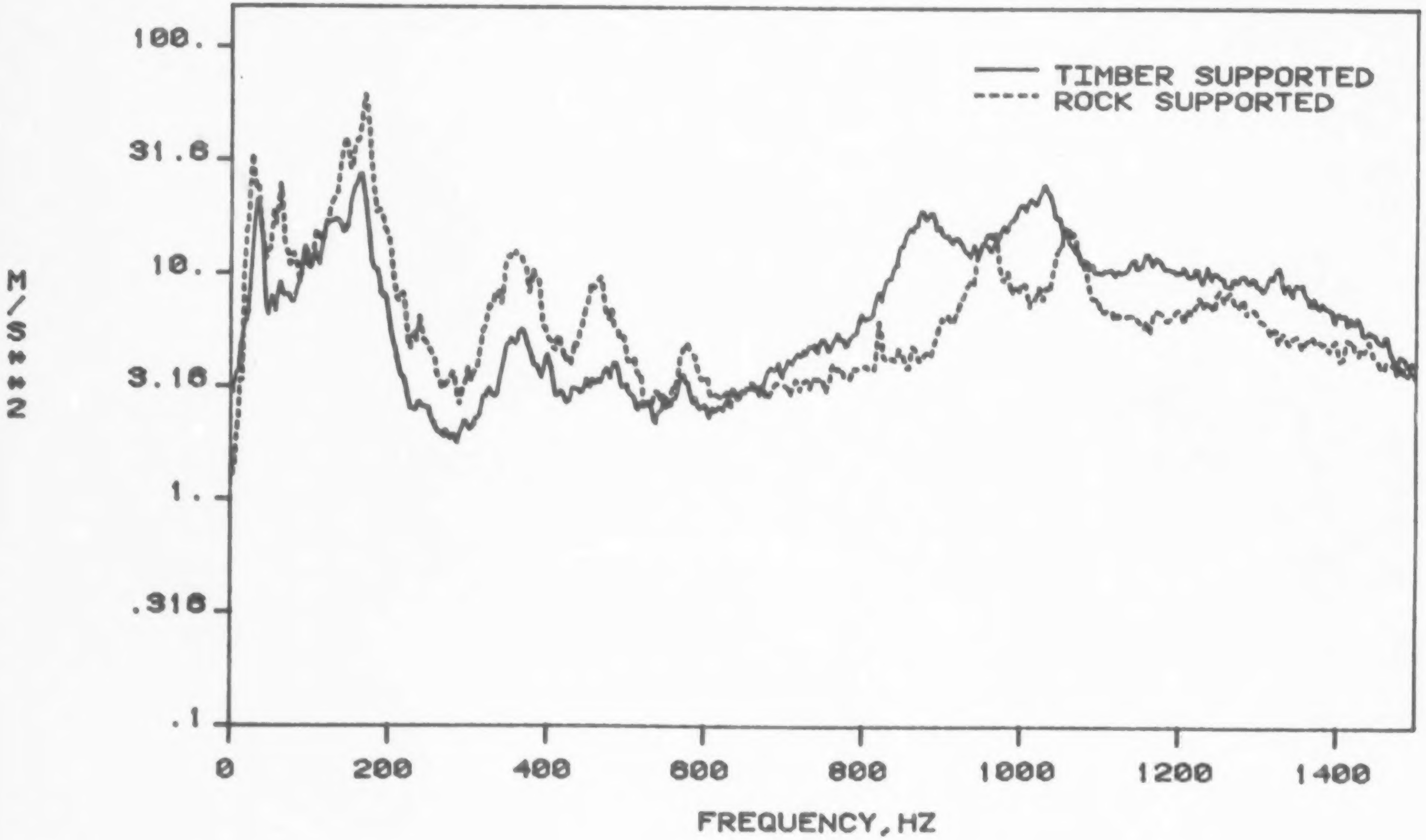


Figure 3.17 COMPARISON OF R.M.S. ACCELERATION SPECTRA FOR ROCK AND TIMBER SUPPORTED STOPER DRILLS (A,4D,15S)

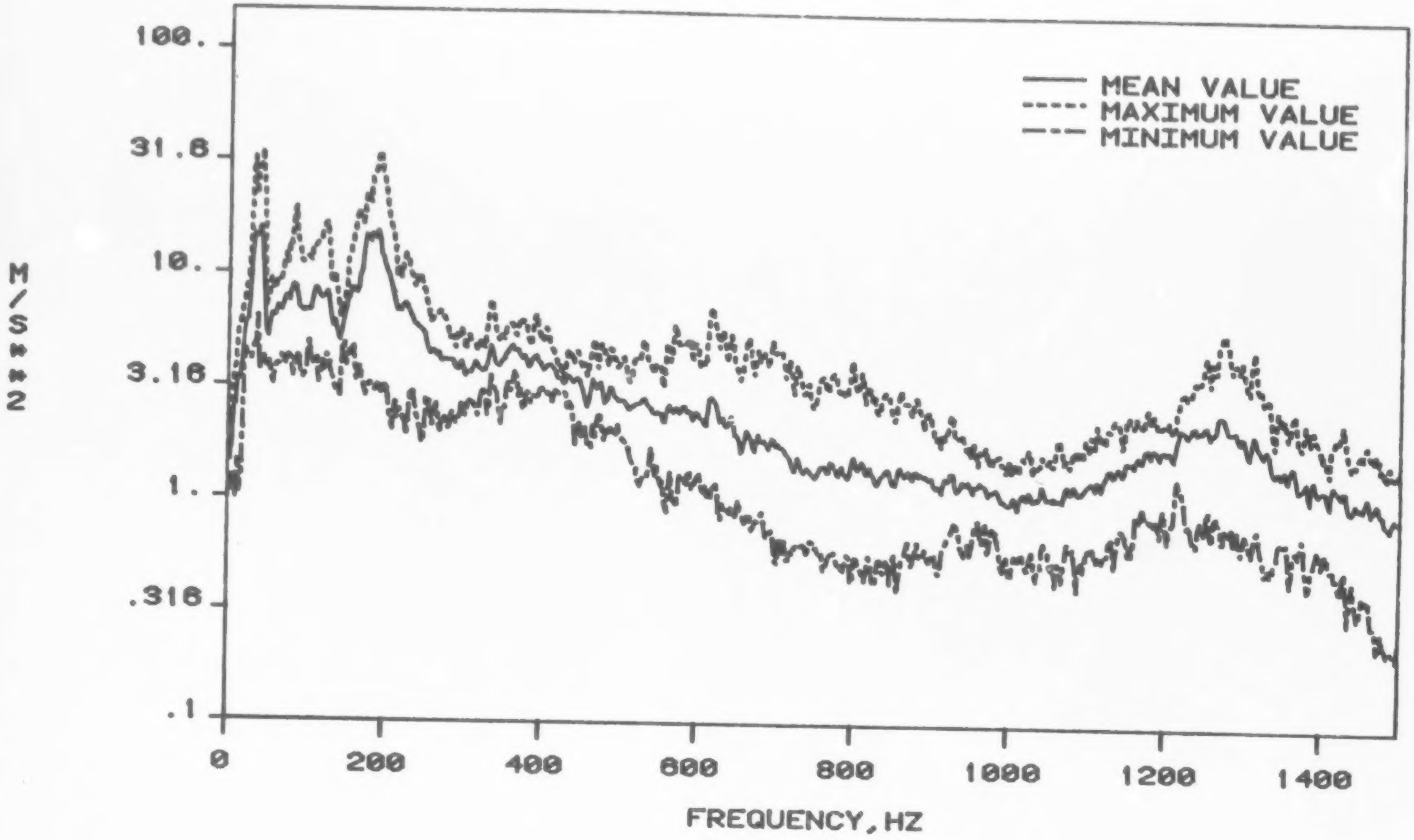


Figure 3.18a R.M.S. ACCELERATION SPECTRA RECORDED ON STOPER HOSE (3D,6S)

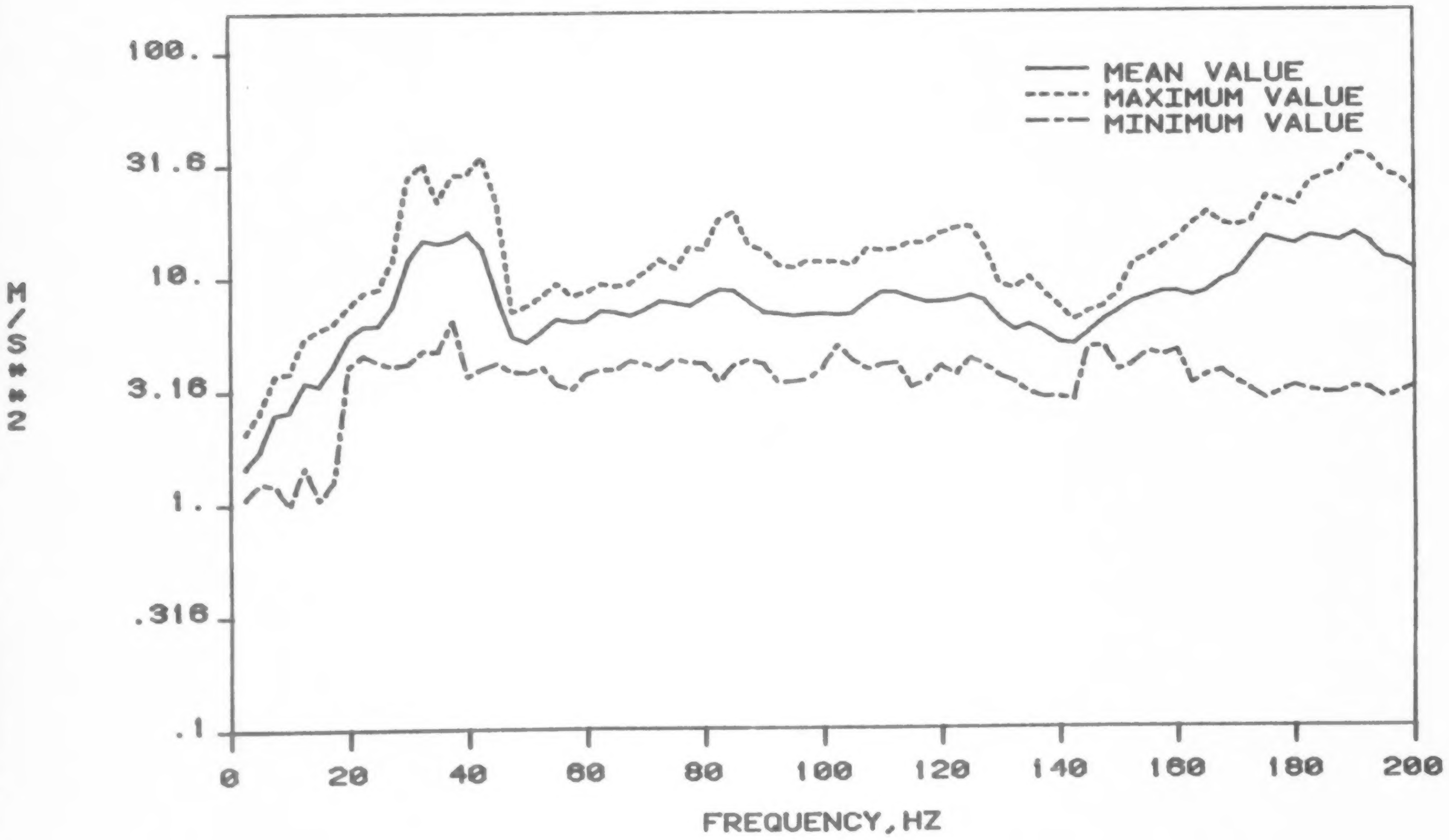


Figure 3.18b R.M.S. ACCELERATION SPECTRA RECORDED ON STOPER HOSE (3D,6S)

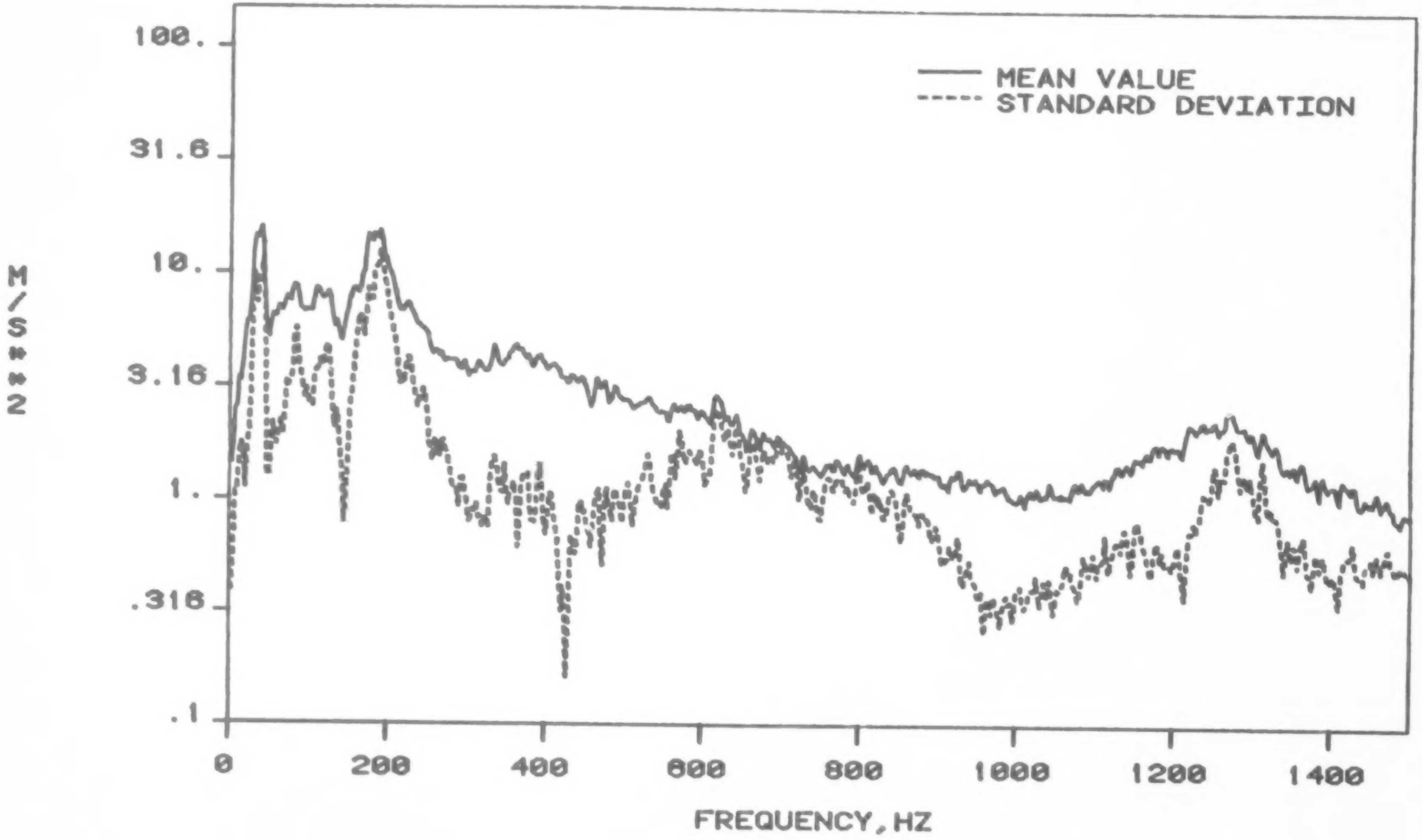


Figure 3.18c R.M.S. ACCELERATION SPECTRA RECORDED ON STOPER HOSE (3D,6S)

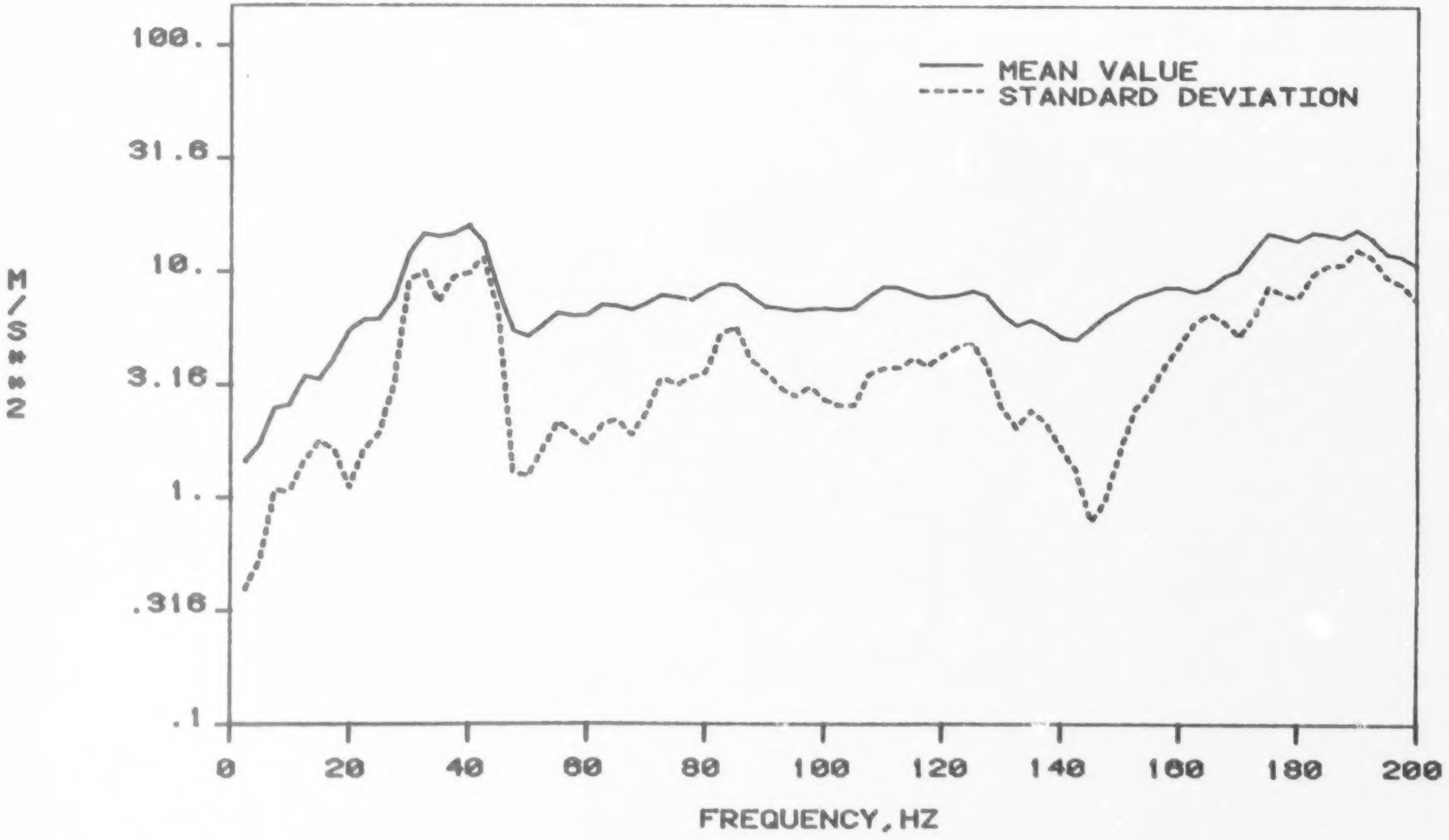


Figure 3.18d R.M.S. ACCELERATION SPECTRA RECORDED ON STOPER HOSE (3D,6S)

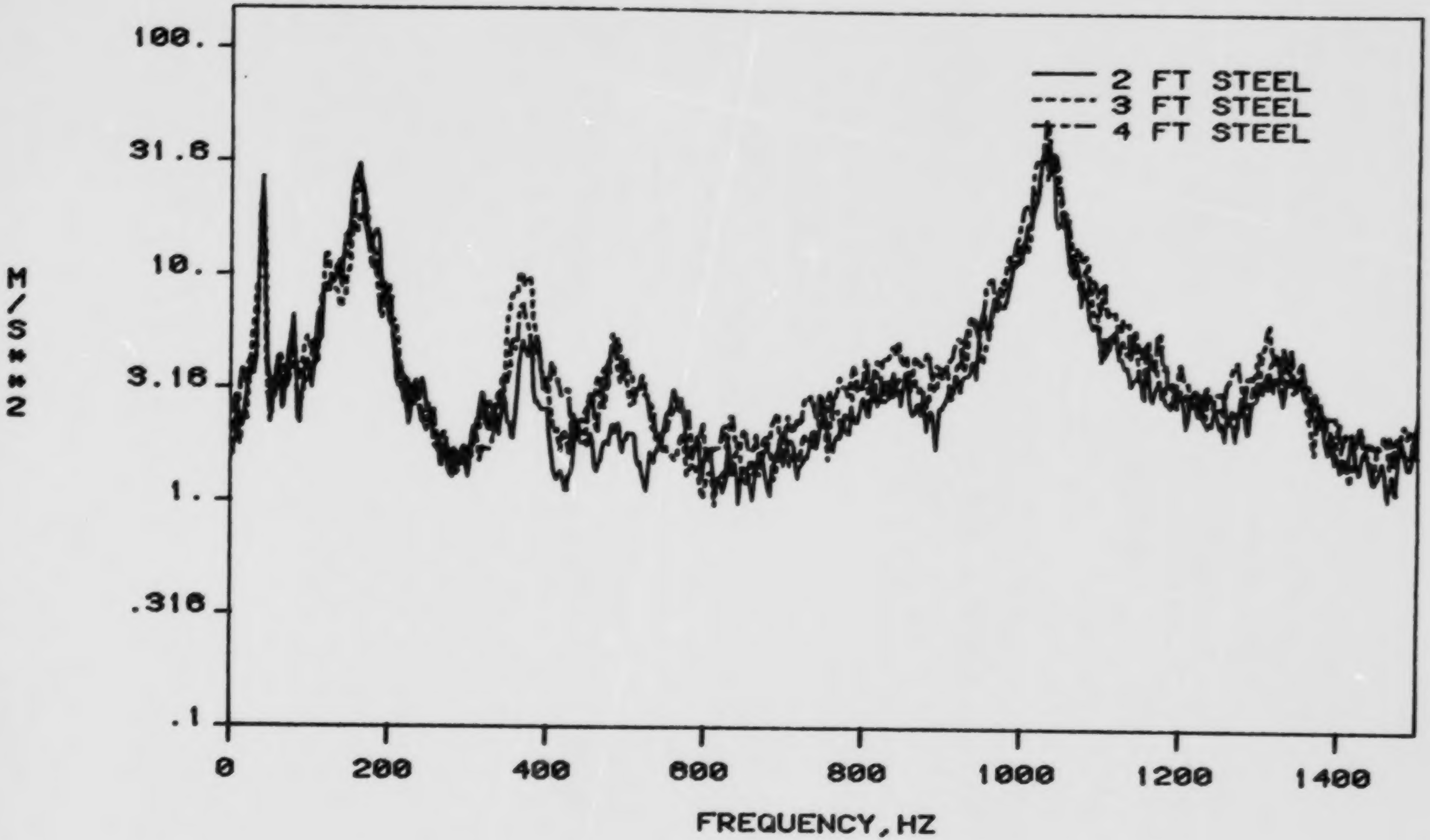


Figure 3.19a R.M.S. ACCELERATION SPECTRA FOR STOPER DRILL WITH DIFFERENT STEEL LENGTHS (1D,3S)

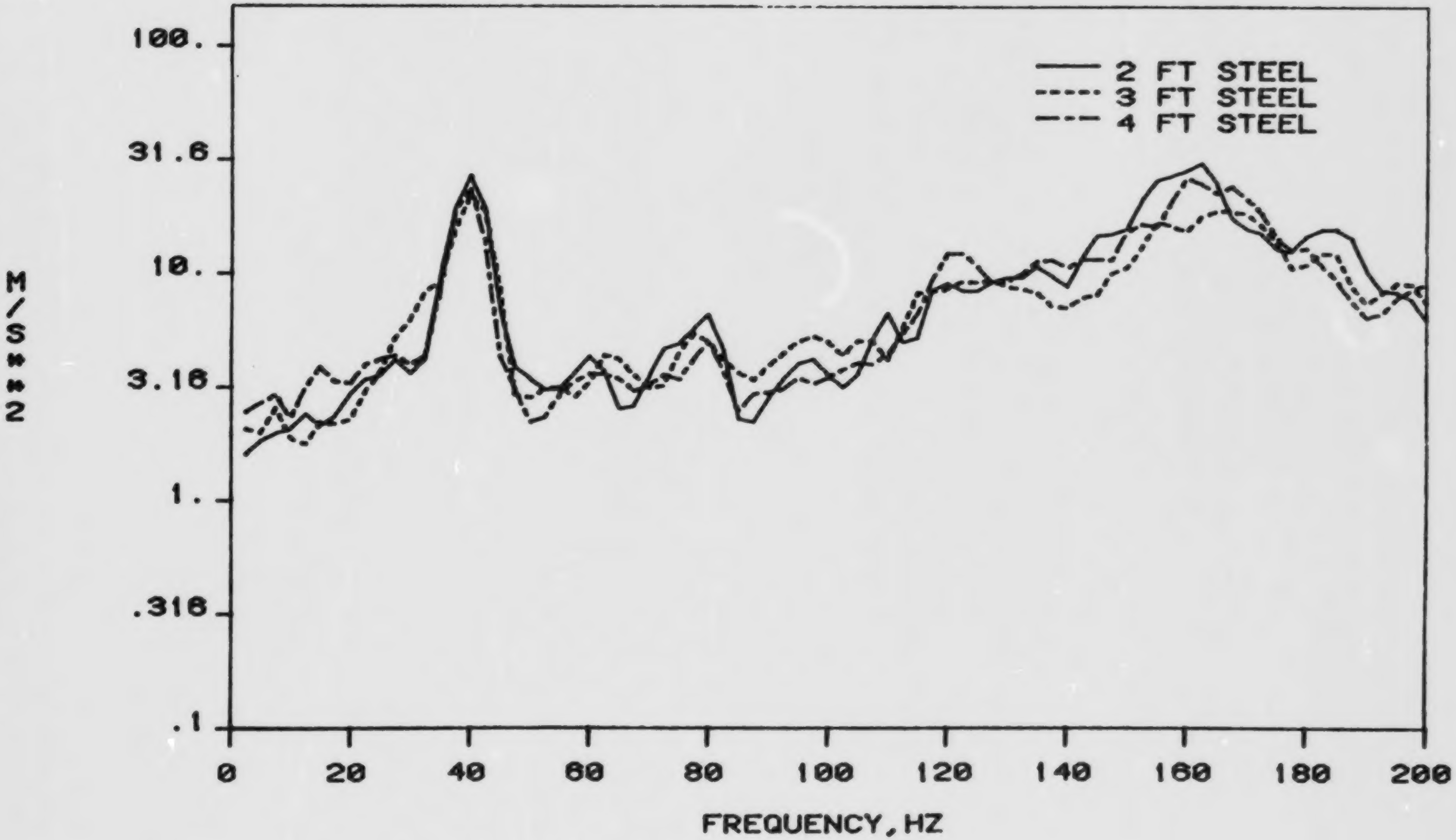


Figure 3.19b R.M.S. ACCELERATION SPECTRA FOR STOPER DRILL WITH DIFFERENT STEEL LENGTHS (1D,3S)

of tests conducted on a timber supported stoper of type A with different steel lengths.

Finally in Figures 3.20 a and b is presented a comparison of the three types of stoper that were tested at the Kimberley mine. The spectrum for drill A represents 5 samples taken from 2 drills; for drill B, 2 samples taken from 1 drill; and for drill D, 3 samples taken from 1 drill. All tests were conducted from a rock base. The results show different vibration spectra but similar vibration levels at low frequencies.

Drilling rates were monitored on 5 jack legs and 4 stopers. The average drilling times were found to be .62 minutes/foot for the jack leg and .55 minutes/foot for the stopers.

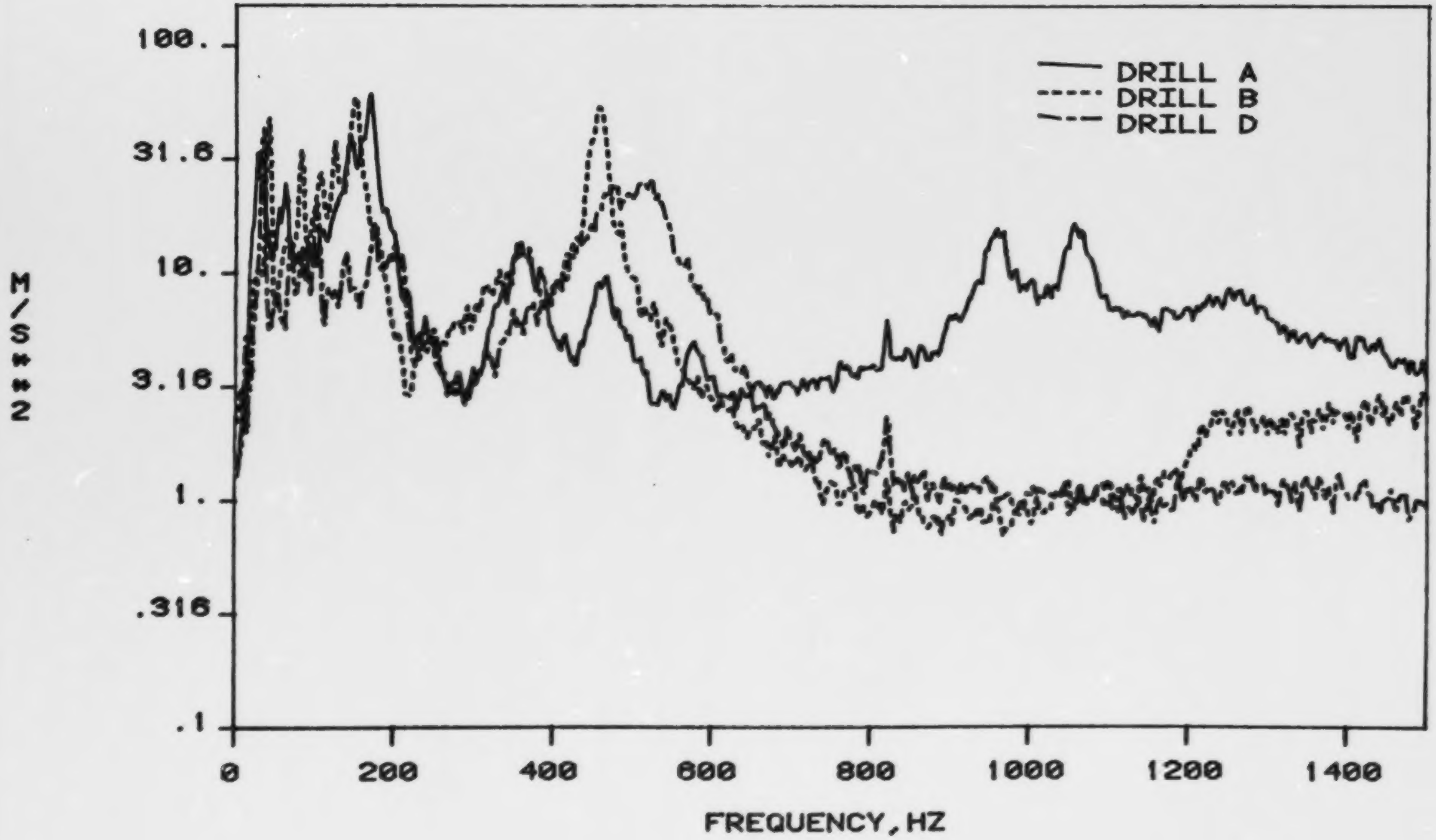


Figure 3.20a COMPARISON OF R.M.S. ACCELERATION SPECTRA FOR DIFFERENT STOPER DRILLS (4D,10S)

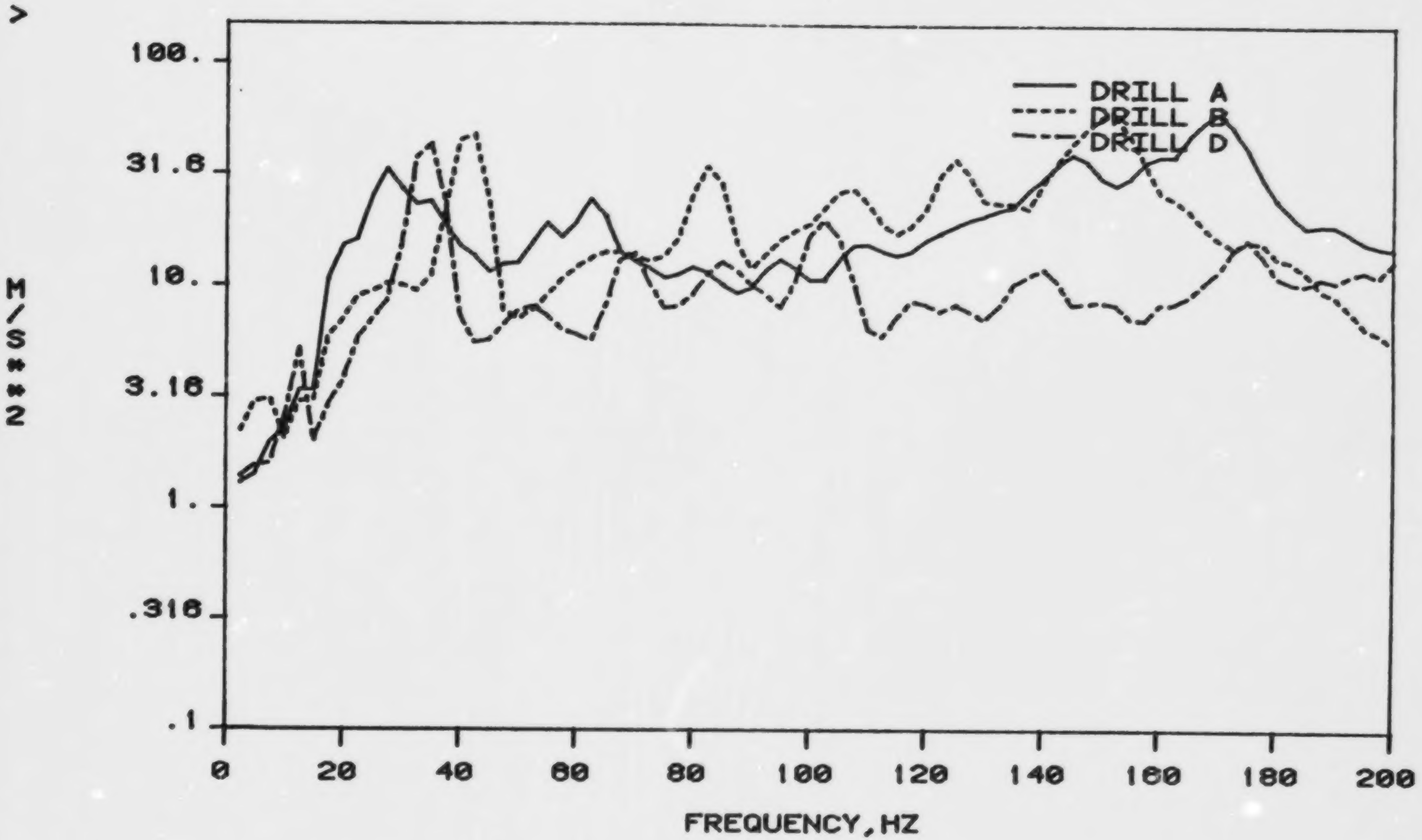


Figure 3.20b COMPARISON OF R.M.S. ACCELERATION SPECTRA FOR DIFFERENT STOPER DRILLS (4D,10S)

3.5 Comparison of Rock Drill Vibration Levels with Code Provisions

As is well recognized, the vibration levels associated with rock drills presently in use in Canadian mines are such that some miners suffer from vibration white finger disease (VWFD). At the present time there is insufficient information available on this problem to enable accurate predictions as to the level of vibration and exposure time that can be tolerated in order to avoid or reduce the incidence of VWFD. To aid in the assessment of the problem and to provide some tentative guide lines the International Standards Organization has issued a draft standard ISO DIS 5349 "Guide For the Measurement and the Assessment of Human Exposure to Vibration Transmitted to the Hand" which was most recently revised in September, 1982. To quote from this Standard:

> "This International Standard together with its annexes provides guidance for the evaluation of hand-transmitted vibration specified in terms of a frequency weighted vibration acceleration and daily exposure time. It does not define the limits of safe exposure.
>
> The guidance proposed in this International Standard is a consensus based upon data available from both practical experience and laboratory experimentation in the field of human response to hand-transmitted vibration. It cannot be taken to delineate completely safe exposure ranges in which vibration diseases cannot occur."

Further

> "General Considerations
>
> The severity of hand-transmitted vibration in working conditions is influenced by:
>
> (a) the frequency spectrum of vibration;
> (b) the magnitude of vibration;
> (c) the duration of exposure per working day and the total exposure time;

(d) the temporal exposure pattern and working method (i.e. length and frequency of work and rest spells; whether tool is laid aside or held idling during breaks in work, etc.); (e) magnitude and direction of forces applied by the operator through his hands to the tool or the workpiece;

(f) the posture of the hand, arm and body position during exposure (angles of wrist, elbow and shoulder joints);

(g) type and condition of vibrating machines, hand tool or workpiece;

(h) area and location of the parts of the hands which are exposed to vibration.

The severity of biological effects of hand-transmitted vibration in working conditions may be influenced by:

(a) the direction of the vibration transmitted to the hand;

(b) the method of working and the operator's skill;

(c) pre-disposing factors in the health of the individual.

The following factors may specifically affect the circulation changes caused by hand-arm vibration:

(a) climatic conditions;

(b) diseases which affect the circulation;

(c) agents affecting the peripheral circulation such as smoking, certain medicines or chemicals in the working environment;

(d) noise.

Although the importance of all factors listed with respect to the generation of vibration disorders is not yet known in sufficient detail, reporting of all factors is considered desirable in order to enable the collection of meaningful exposure histories. It is also important to report the measurement procedure and the statistical techniques used to evaluate the vibration data".

As may be recognized from these comments the factors affecting the development of VWFD may be varied. However this standard contains an annex: "Guidelines for the evaluation of hand-transmitted vibration exposure" which may be used to assess the potential of a given vibration level/dose time to cause VWFD. These guidelines are expressed in terms of a frequency weighted four hour energy equivalent acceleration which is related to time exposure before the onset of VWFD symptoms as shown in Figure

3.21, where the percentile figures refer to the percentage of exposed workers that are likely to suffer from the symptoms. The weighted acceleration a_{hw} is defined in terms of one third octave (or octave) band levels as

$$a_{hw} = \sqrt{\sum_{i=1}^{n} (K_i \, a_{hi})^2}$$

where

K_i is the weighting factor for the ith one third octave (octave) band.

n is the number of one third octave (octave) bands.

For one third octave bands K_i is defined by Table 3.1.

If the period of exposure does not correspond to 4 hours then the equivalent four hour weighted acceleration is determined from the formula

$$a_{hw(4)} = \left(\frac{T}{4}\right)^{1/2} a_{hw(T)}$$

where $a_{hw(4)}$ is the frequency weighted four hour energy equivalent acceleration, and $a_{hw(t)}$ is the frequency weighted acceleration measured, and T is the time in hours that the operator is exposed to the level $a_{hw(T)}$. It is the value of $a_{hw(4)}$ that is used in Figure 3.21 to determine the time exposure before the onset of symptoms.

In order to help assess the accuracy of the information contained in this standard, the data collected during this study was analysed as specified. The tape recorded data was frequency analysed using the Nicolet 660A on a range 0-2000 Hz which provided

Frequency (Hz)	Weighting Factor (K_i)
6.3	1.0
8.0	1.0
10.0	1.0
12.5	1.0
16	1.0
20	0.8
25	0.63
31.5	0.5
40	0.4
50	0.3
63	0.25
80	0.2
100	0.16
125	0.125
160	0.1
200	0.08
250	0.063
315	0.05
400	0.04
500	0.03
630	0.025
800	0.02
1000	0.016
1250	0.0125

Table 3.1 Values of K_i for conversion of one third octave band measurements to weighted measurements

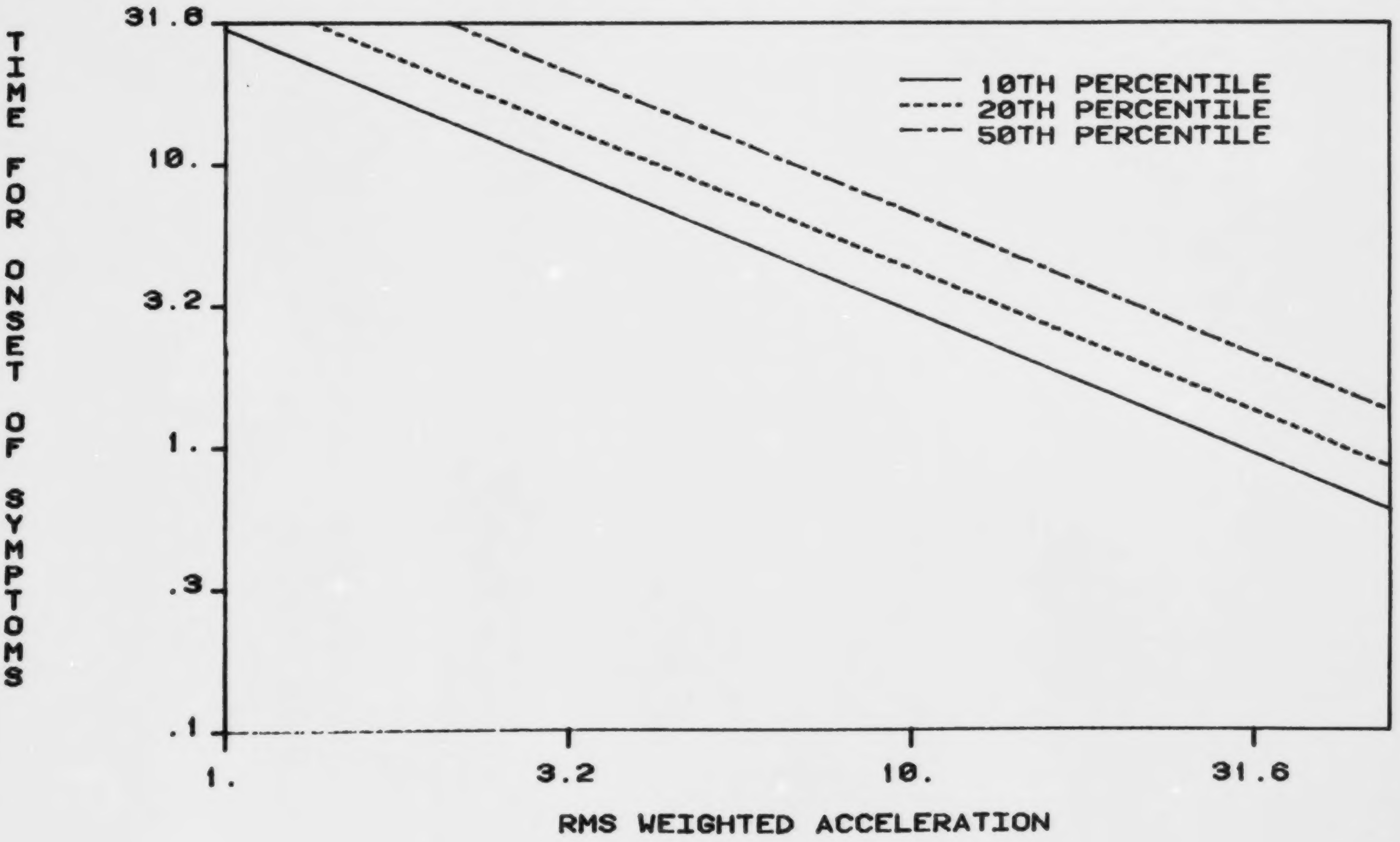


Figure 3.21 TIME IN YEARS FOR ONSET OF VWFD SYMPTOMS VERSUS WEIGHTED ACCELERATION LEVEL(m/s2)

a frequency reading every 2.5 Hz. This data in the range 5-1500 Hz was then weighted by a factor of 16 divided by the frequency in Hz for the range 16-1500 Hz, and by a factor 1 in the range 5 - 16 Hz. The weighted acceleration level was then calculated according to the standard. The program used for this computation (AHW) is given in the Appendix.

As reported in Section 3.3 the measurements were taken to ascertain the time exposure received by miners. These results indicated a maximum exposure of 1.5 hours per shift. Thus the equivalent four hour weighted acceleration is given by

$$a_{hw(4)} = \left(\frac{1.5}{4} \right)^{1/2} a_{hw} = .61\, a_{hw} \quad .$$

Tables 3.2 and 3.3 present the results of the calculation of $a_{hw(4)}$ cross referenced to the graphs on which the spectra of the samples have been plotted.

Figure	Equivalent four hour weighted acceleration	Mean
3.1	19, 19, 20, 19	19
3.2	19, 19, 16	18
3.3	18, 29, 19, 27, 25, 19, 18, 20, 23, 30, 22, 27, 19, 19, 20, 19, 16, 17, 28, 24, 19, 19, 22, 19 19, 16, 17, 18, 17, 19, 19, 14, 14, 17, 17, 25 33, 11, 22, 19	20
3.4	24, 19, 24, 22, 19	22
3.5	18, 29, 19, 30, 16, 17, 19, 19, 16, 25, 11	20
3.6	27, 25, 20, 22, 28, 24, 22, 17, 18, 17, 33, 22	23
3.8	29, 24, 20, 17, 21, 19, 34	24
3.9	19	19
3.10	27, 19, 19, 27, 25, 26, 22, 16, 15, 21, 20, 17 22, 19, 20, 12, 18, 13, 19, 12, 14, 15, 16, 14 19, 19, 17, 14, 14, 32, 27, 21, 29, 21, 22, 24	20

Table 3.2 Weighted acceleration levels at Westmin Mine.

Figure	Equivalent four hour weighted acceleration	Mean
3.11	14, 14, 18, 20, 25, 16, 22, 27	19
3.12	14, 17, 17, 19, 20, 19, 19, 30, 30, 19, 19, 20	20
3.14(C)	21	21
3.14(D)	29	29
3.15	32, 30, 28, 13, 12, 12, 19, 17, 16,16	19
3.16	30, 33, 29, 34, 33	32
3.18	16, 14, 18, 11, 13, 17	15
3.20(A)	30, 33, 29, 34, 33	32
3.20(B)	29, 24	26
3.20(C)	21, 24, 20	22

Table 3.3 Weighted acceleration levels at Kimberley Mine.

As may be seen from the results quoted in Table 3.3 the jack legs of type A (Figure 3.11) and B (Figure 3.12) gave mean weighted acceleration levels of virtually the same value, 20 and 19 m/s^2 respectively. The rock supported stopers of type A (Figure 3.16) gave much higher levels 32 m/s^2 whereas the timber supported stopers (Figure 3.13) gave levels comparable with the jack leg drills. Stopers type B and D gave lower levels than A but there are insufficient samples to attach much weight to the result.

According to ISO DIS 5349 a weighted acceleration level of 20 m/s^2 i.e., that of the jack leg drill would give rise to the onset of VWFD after approximately 1-1/2 years in 10% of those exposed and after 3-1/2 years in 50% of the cases. The level of 32 m/s^2 measured for the rock supported stopers would lead to the onset of symptoms after approximately 1 year in 10% of the cases and after approximately 2-1/2 years in 50% of the cases. The corresponding times associated with hose vibration levels are 2 and 5 years.

The perception amongst miners is that jack leg drills are more likely to cause VWFD than stoper drills. This does not entirely correspond to the predictions quoted above although it must be remembered that when using a stoper the driller is more likely to release the handle during drilling than when using a jack leg drill.

3.6 Vibration Survey of the Refiner Mill and Compressor Room at the Westmin Mine

A vibration survey was conducted at the Westmin Mine of the vibration levels of various items of machinery and of various locations where mine personnel worked. The purpose of this work was to record the vibration level of areas where personnel are exposed to whole body vibration and also to record spectra for particular types of mining equipment.

With regard to whole body vibration ISO 2631 "Guide for the evaluation of human exposure to whole body vibration" makes recommendations concerning the effects of such vibration:

> " This International Standard defines and gives numerical values for limits of exposure for vibrations transmitted from solid surfaces to the human body in the frequency range 1 - 80 Hz. It may be applied, within the specified frequency range, to periodic vibrations and to random or non periodic vibrations with a distributed frequency spectrum."

The Standard defines three boundaries for considering the effect of the vibration in terms of a one third octave band analysis. These boundaries are (i) "Fatigue-decreased proficiency boundary", (ii) "Exposure limit", and (iii) "Reduced comfort boundary". In the present work only the "fatigue-decreased proficiency boundary" will be considered.

In order to obtain a one-third octave band analysis the tape recorded data was analysed by the Nicolet 660A on a frequency scale 0 - 200 Hz and these results were used to generate a one third octave analysis using the program THIRD OCTAVE given in the Appendix.

The fatigue-decreased proficiency boundary should, according to ISO 2631 be used as the guiding limit where the primary concern is to maintain the working efficiency of a machine operator exposed to the vibration. The levels that have been used for comparison purposes in the report are based upon an exposure period of 8 hours.

Whole body vibration measurements were made on the floor at various points om the refiner area and in the compressor room. Readings were also taken on those items of equipment in these areas that give rise to the vibrations. The equipment measured in the refiner area consisted of a jaw crusher, a cone crusher, a rod mill and two ball mills. In Figure 3.22a is plotted, to a logarithmic frequency scale, the narrow band acceleration spectra obtained from the spectrum analyzer, the third octave level, and the ISO "fatigue-decreased proficiency boundary" for the vibration levels measured on the platform of the jaw crusher. The third octave bands with centre frequencies of 10 and 12.5 Hz both slightly exceed the recommended levels. The interpretation of the boundary is that if any third octave band exceeds the boundary level then the vibration level is such that those exposed to such levels for a continuous 8 hour period are likely to suffer from a reduced level of efficiency. In Figure 3.22b the platform around the jaw crusher is shown as well as the location of the accelerometer.

Readings were taken on the top of the cone crusher and on its concrete base (see Figure 3.23a) and these results are presented in Figure 3.23b and c respectively. The readings were taken at

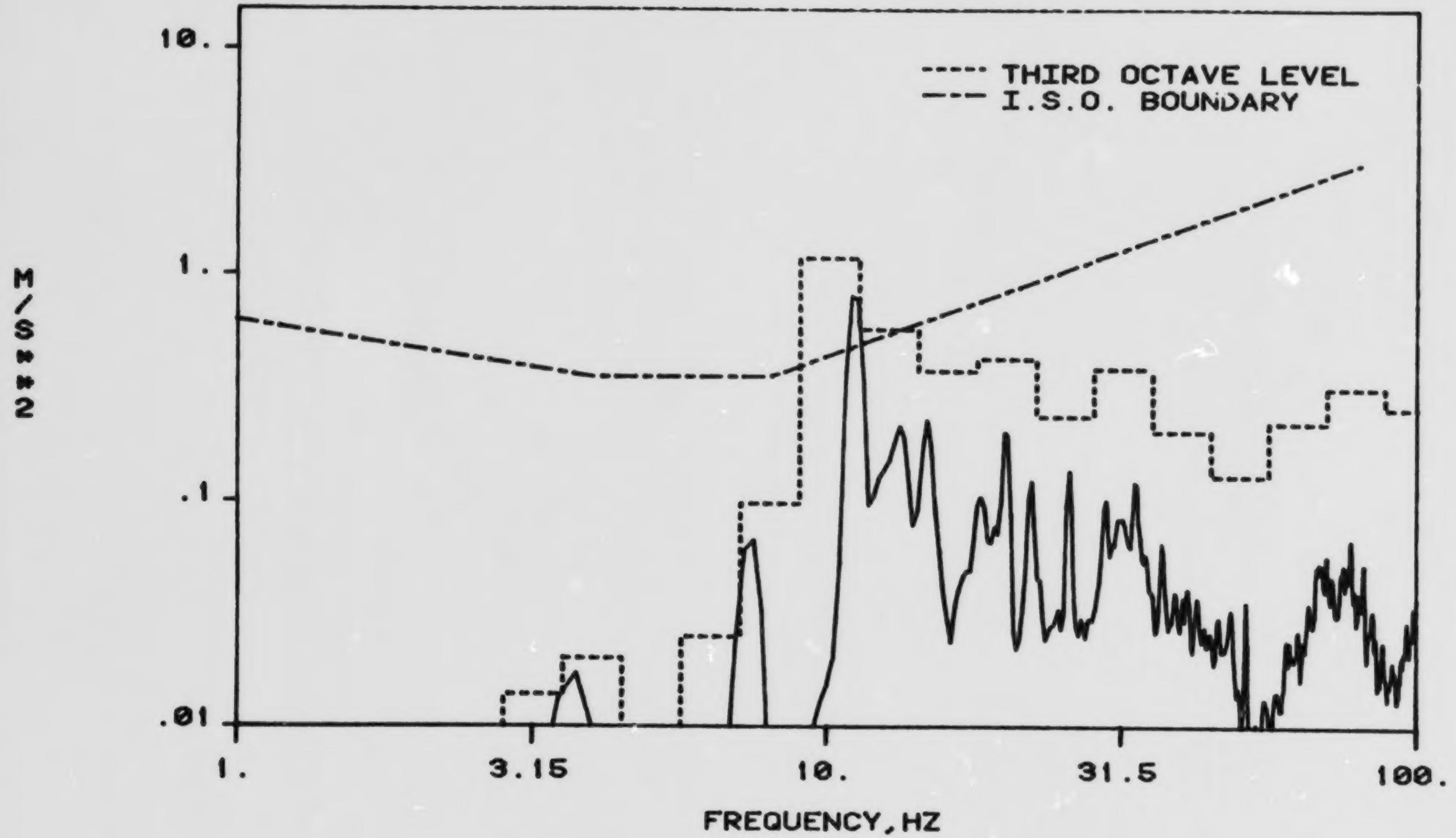


Figure 3.22a R.M.S. ACCELERATION SPECTRA FOR PLATFORM AROUND JAW CRUSHER

Figure 3.22b JAW CRUSHER PLATFORM

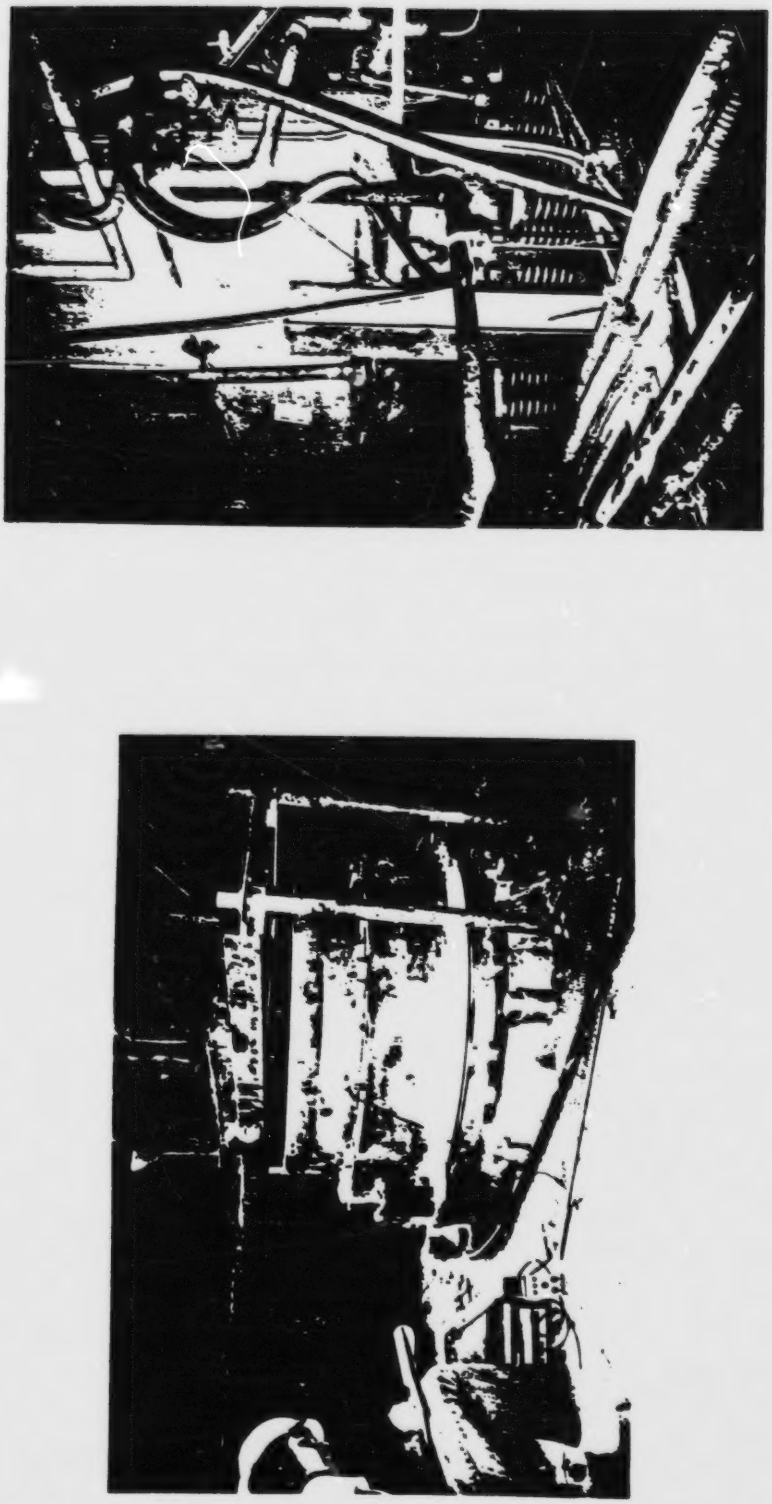


Figure 3.23a LOCATION OF READINGS ON CONE CRUSHER AND ITS BASE

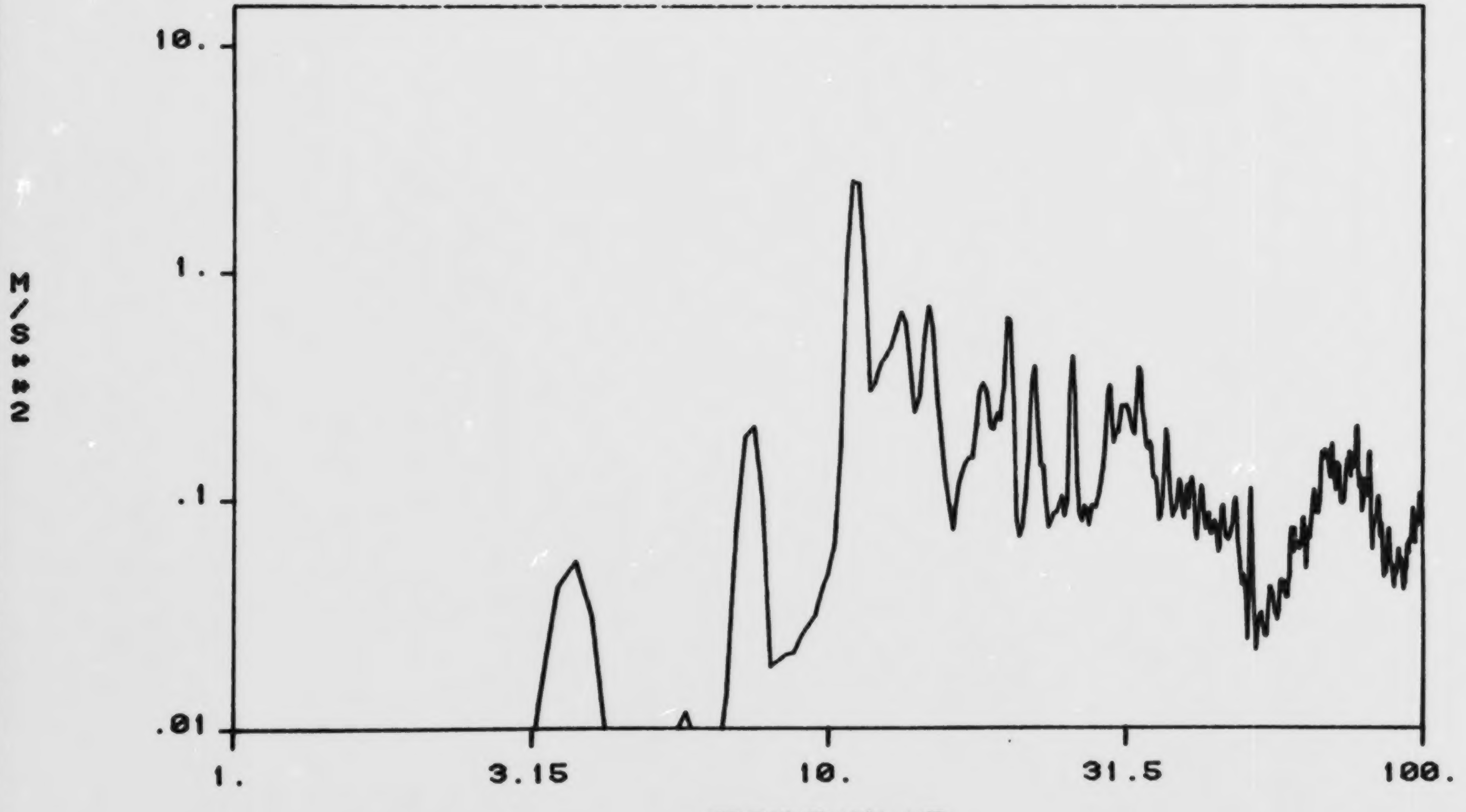


Figure 3.23b R.M.S. ACCELERATION SPECTRUM ON CONE CRUSHER

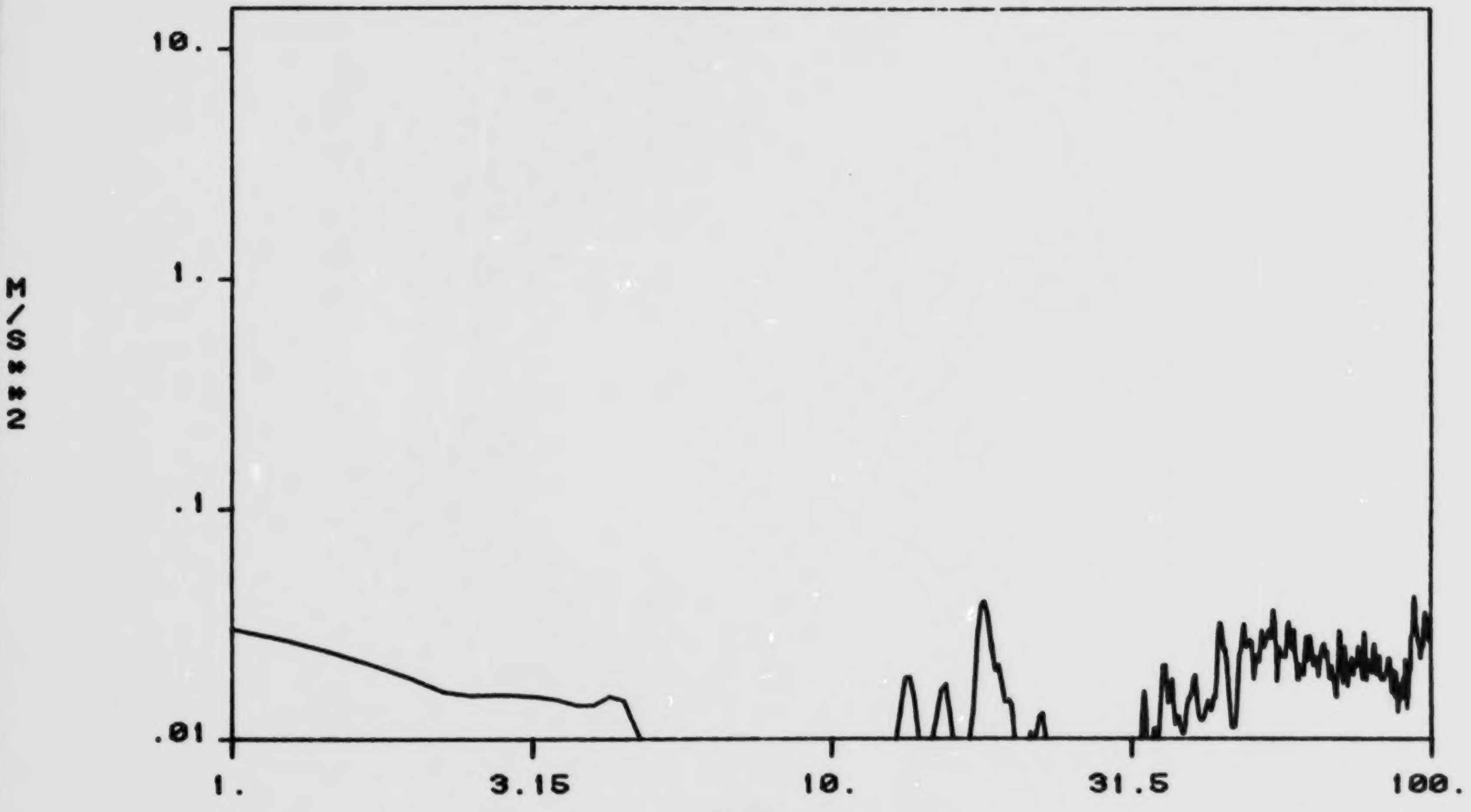


Figure 3.23c R.M.S. ACCELERATION SPECTRUM ON CONE CRUSHER

different times but in both cases with the crusher full. As can be noted the isolation system is effective in reducing the vibration levels.

Figure 3.24a presents the results taken on the floor near the rod mill, in Figure 3.24b the results taken on the bearing housing of the rod mill are given and in Figure 3.24c the location of these tests is shown. The levels recorded were quite low. In Figures 3.25 a-c equivalent results are given in the location of one of the ball mills, again the vibration levels are low.

Higher vibration levels were found on the slusher-platform loading area, and these results are presented in Figures 3.26a,b. Although the "fatigue-decrease proficiency boundary" has been slightly exceeded, in this case the operator is not in fact subjected to continuous vibration exposure.

Low levels of vibration were also recorded in zinc flotation area and these are recorded in Figure 3.27a.

In the compressor room readings were taken on the base of a diesel engine, on the isolated concrete foundation and on the floor adjacent to the isolated foundation. Figure 3.28a shows the location of these measurements and the results are presented in Figure 3.28 b-d. The engine had an operating speed of 1200 RPM (20Hz) and the harmonics of this frequency are clearly evident in the results recorded. The isolation system employed is effective in reducing the vibration levels.

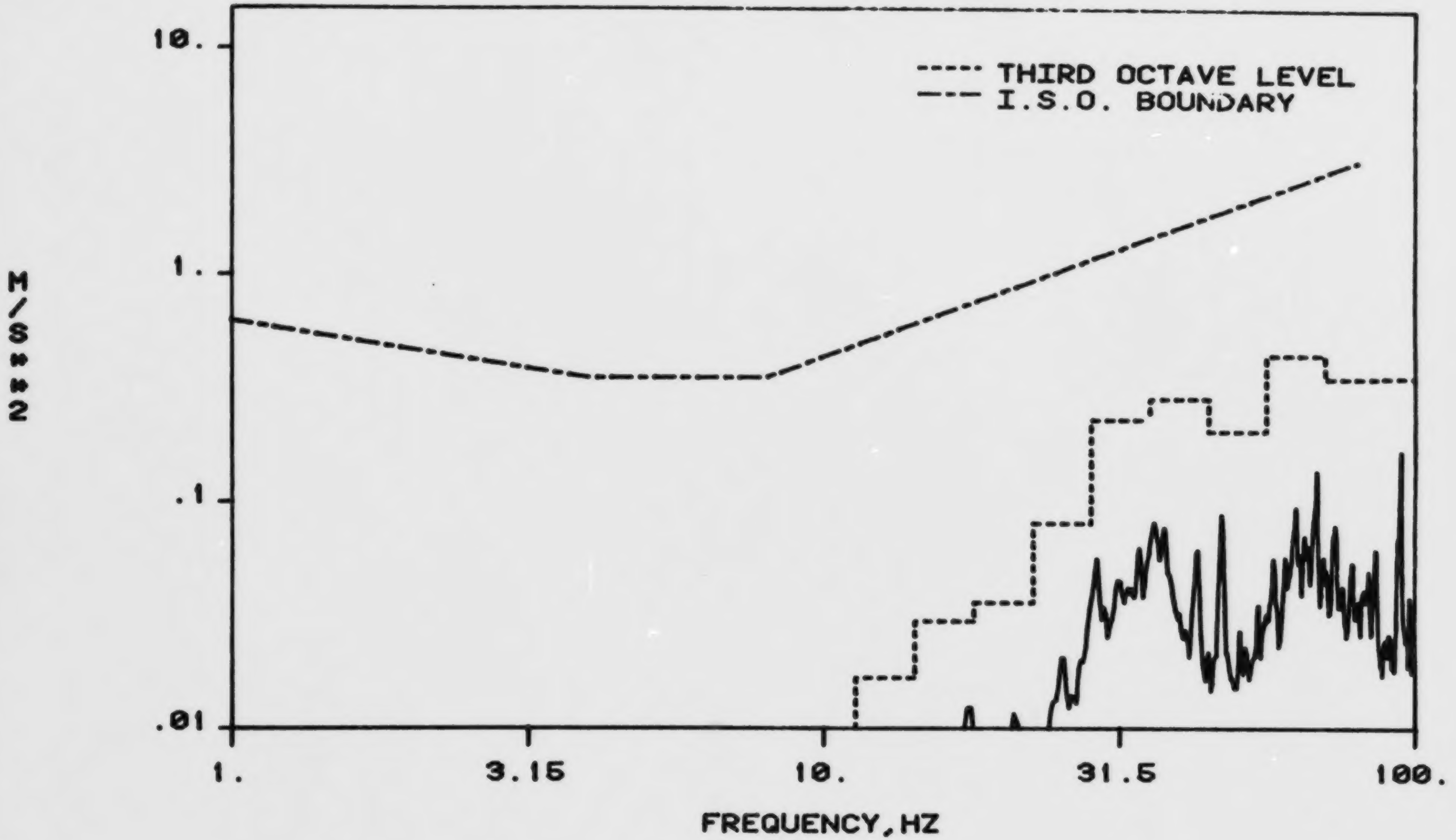


Figure 3.24a R.M.S. ACCELERATION SPECTRA FOR FLOOR ADJACENT TO ROD MILL

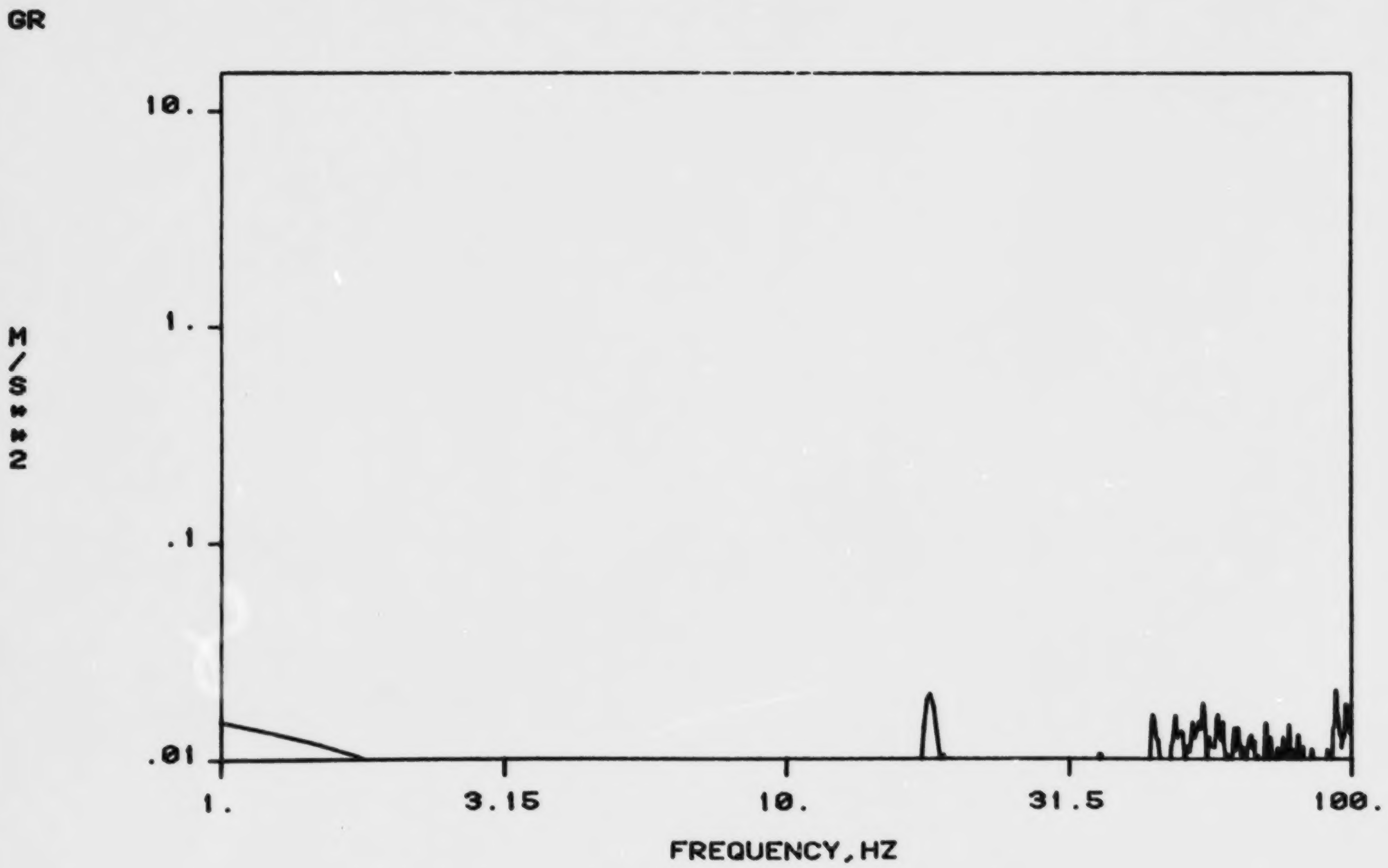


Figure 3.24b R.M.S. ACCELERATION SPECTRA ON BEARING HOUSING OF ROD MILL

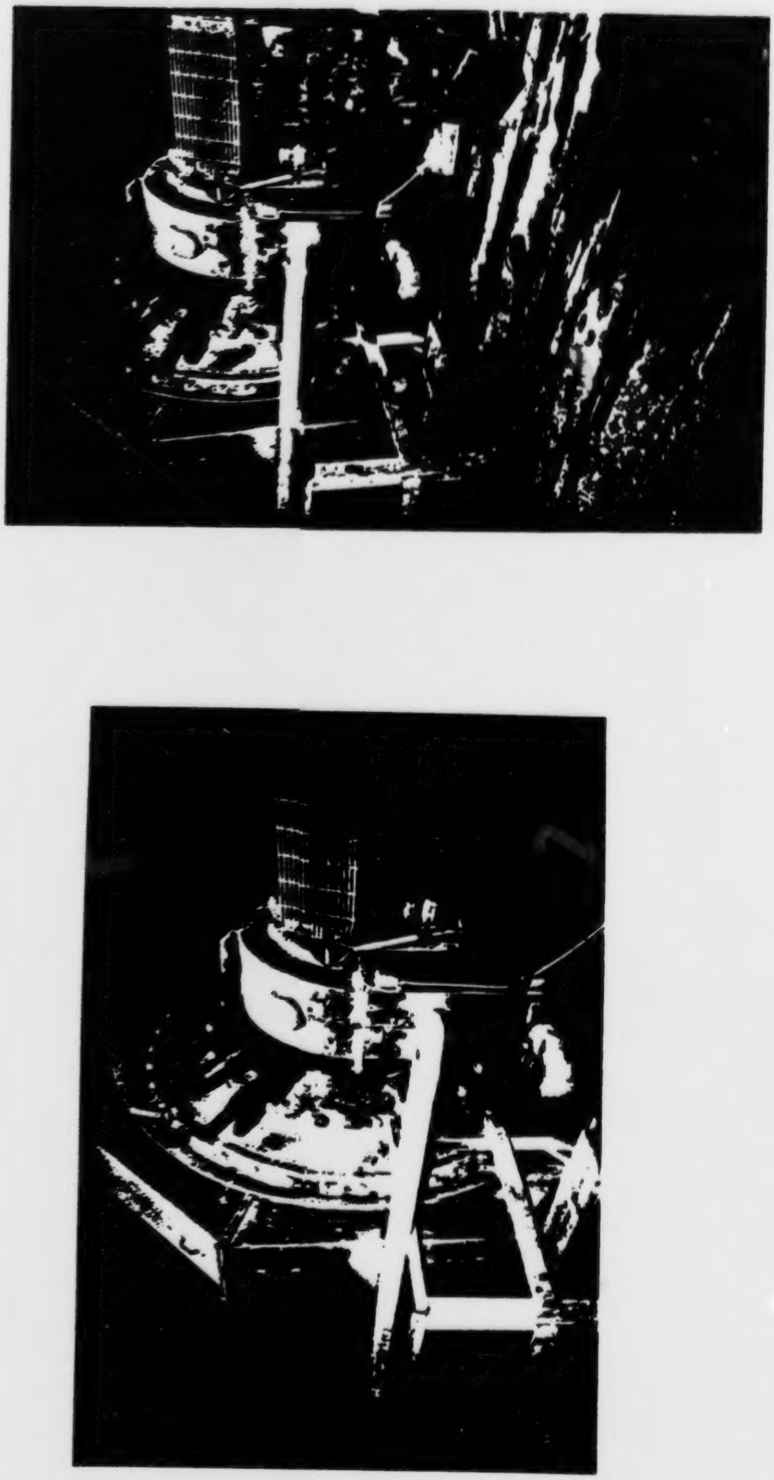


Figure 3.24c LOCATION OF ACCELEROMETER FOR ROD MILL TESTS

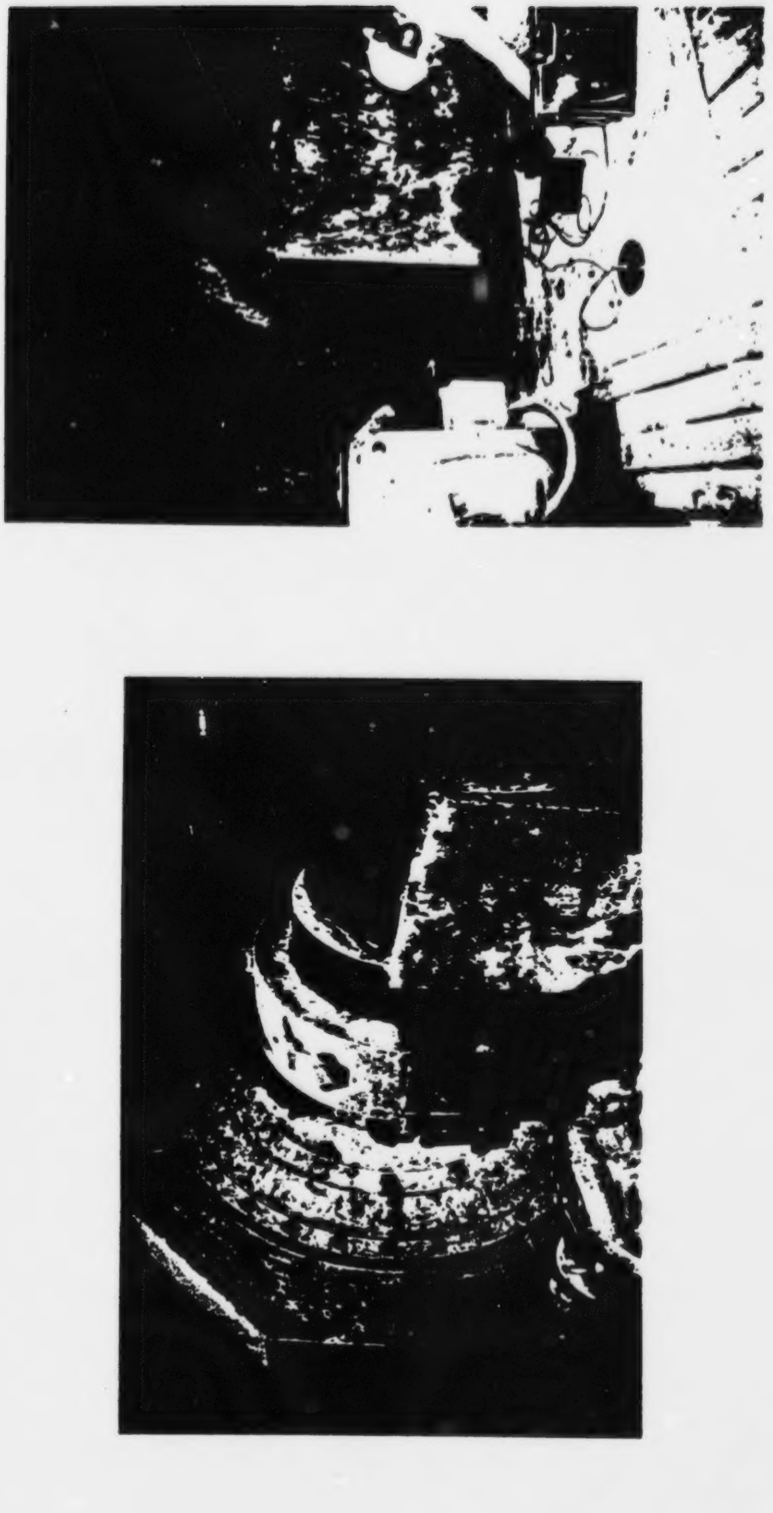


Figure 3.25a LOCATION OF READINGS FOR BALL MILL

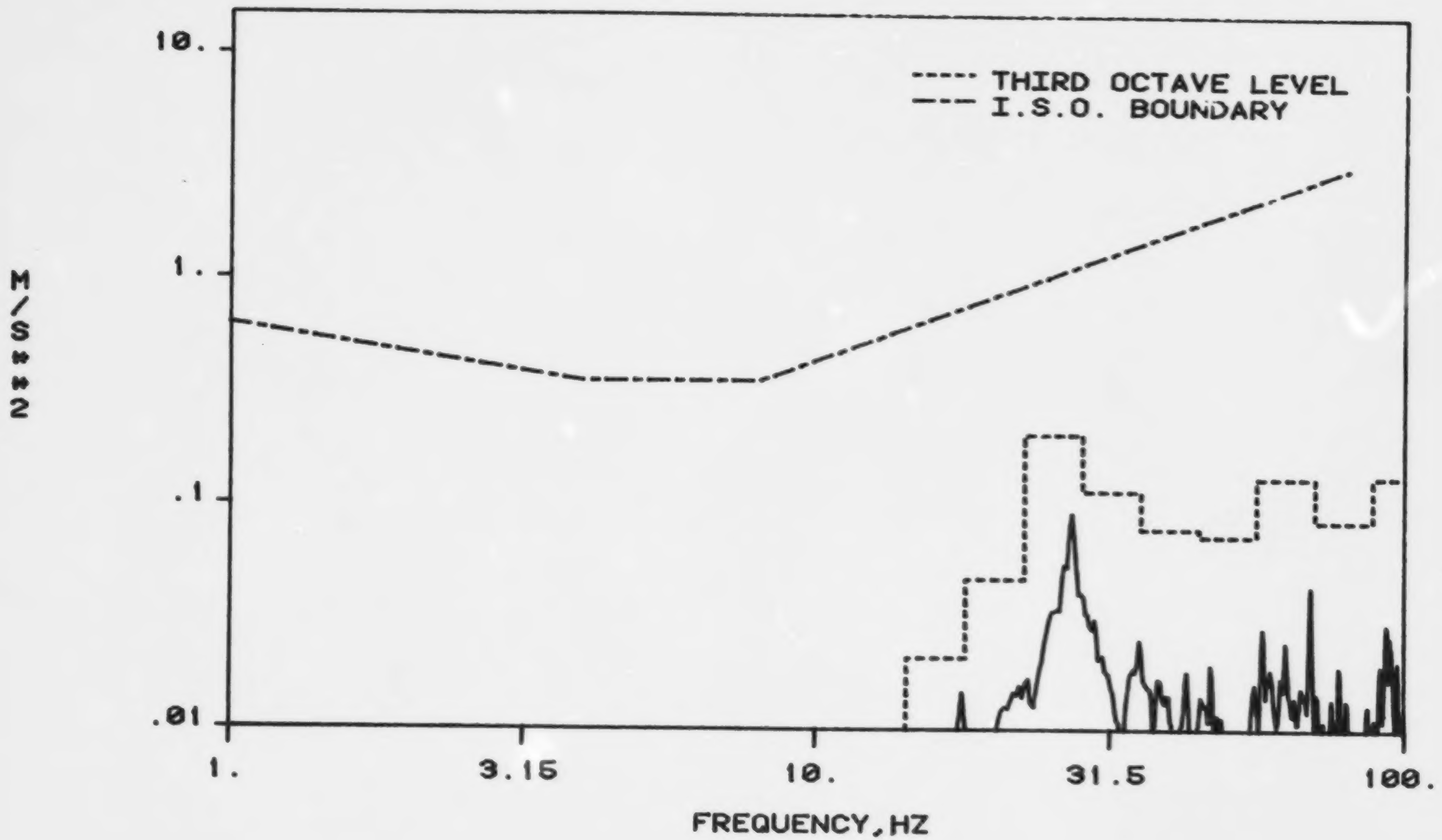


Figure 3.25b R.M.S. ACCELERATION SPECTRA FOR FLOOR NEAR BALL MILL

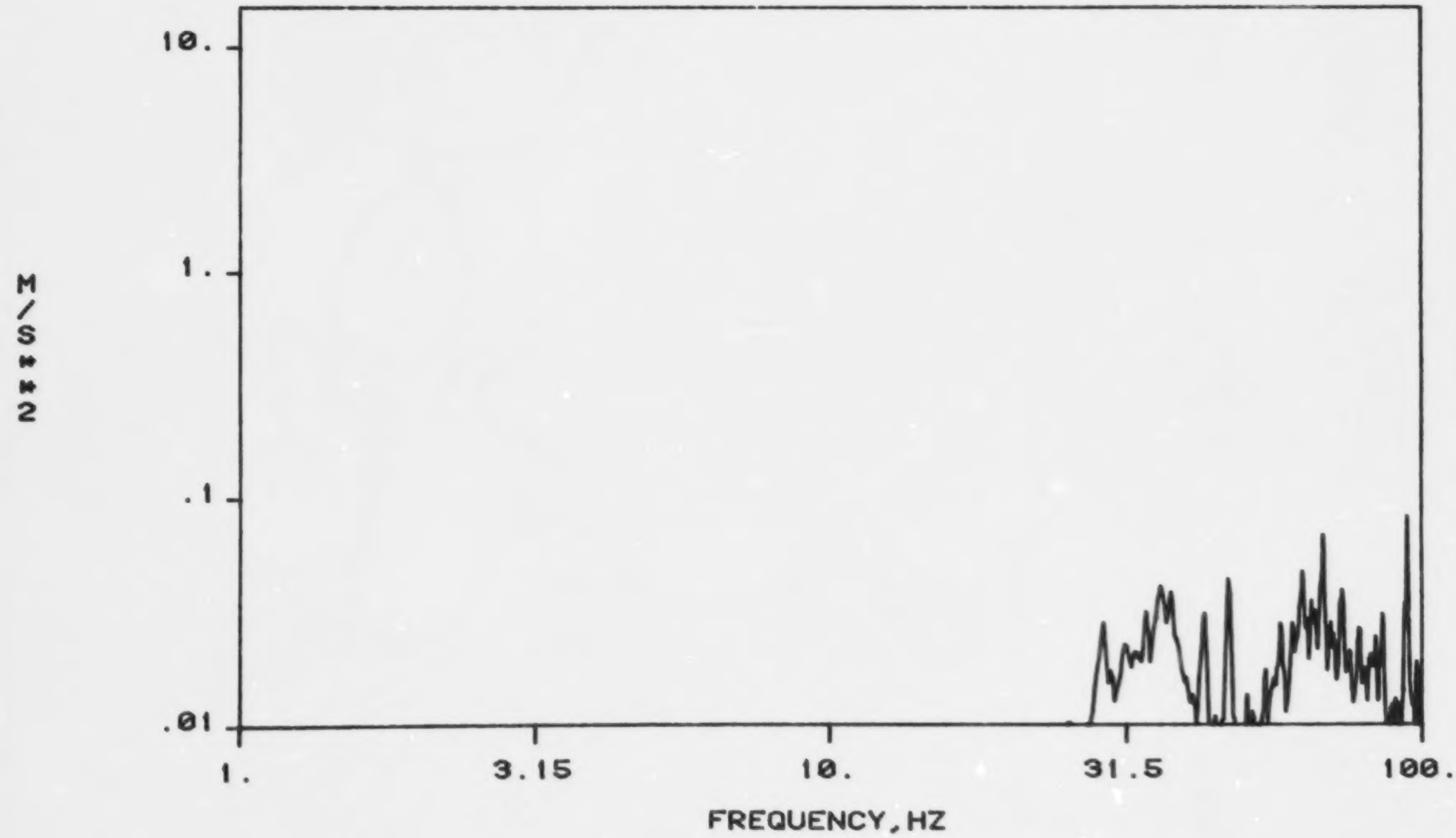


FIGURE 3.25c R.M.S. ACCELERATION SPECTRA FOR BALL MILL

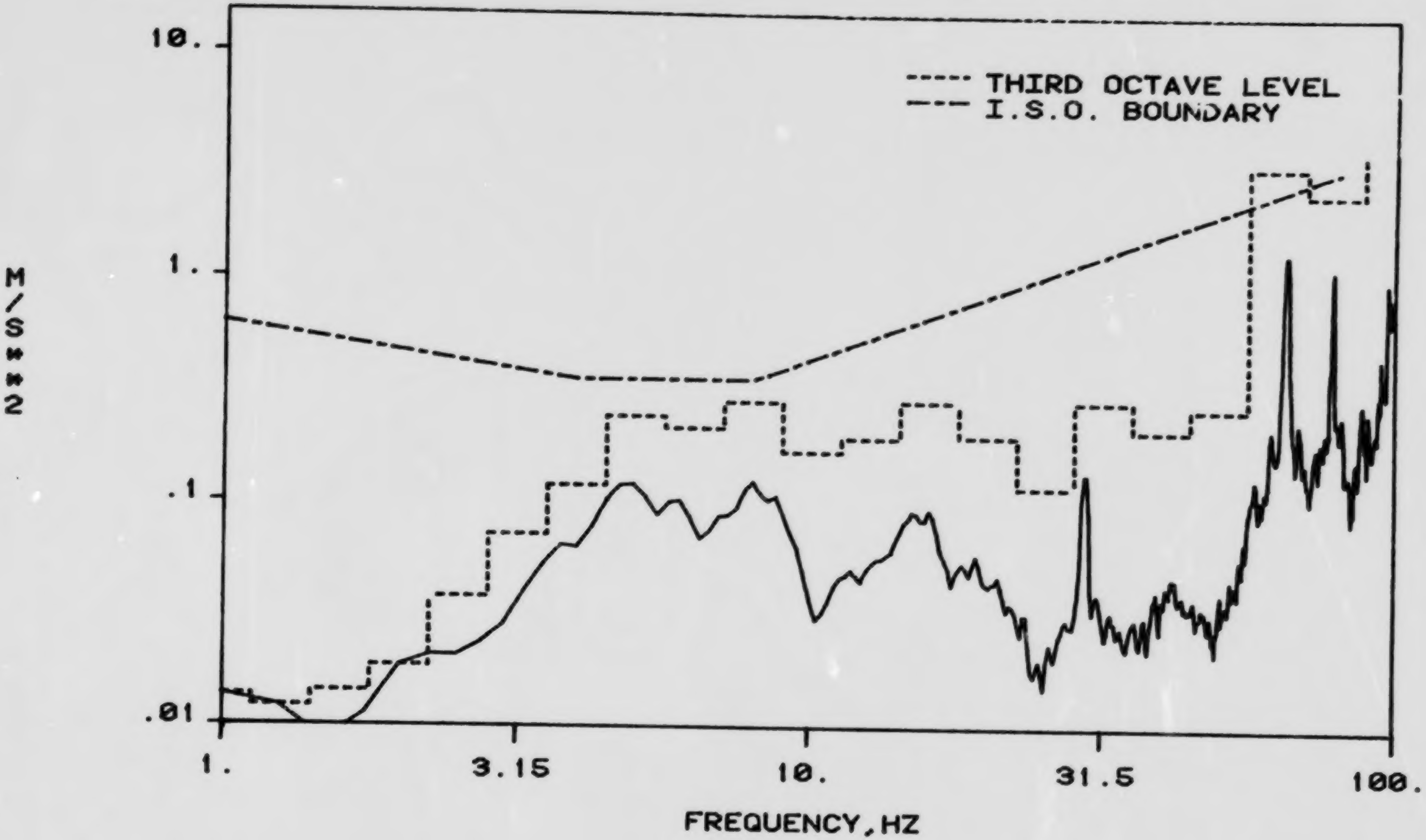


Figure 3.26a R.M.S. ACCELERATION SPECTRA FOR SLUSHER-PLATFORM

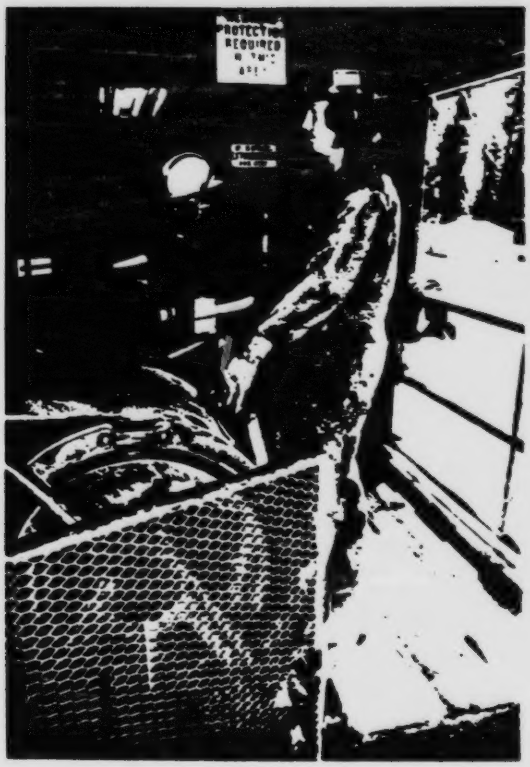

PROTECTION
REQUIRED
IN THIS
AREA

Figure 3.26b SLUSHER PLATFORM

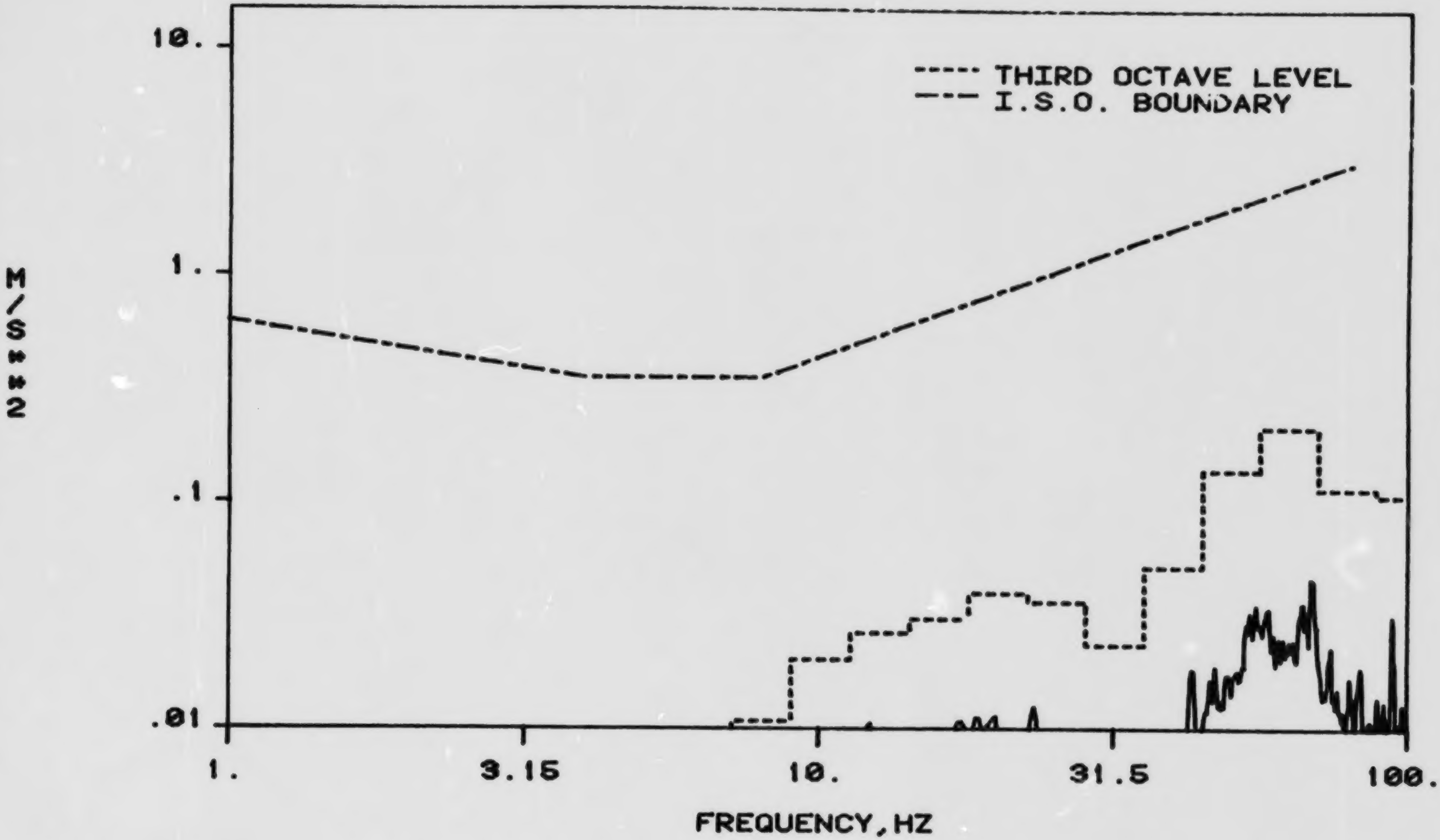


Figure 3.27a R.M.S. ACCELERATION SPECTRA ON FLOOR IN ZINC FLOTATION AREA

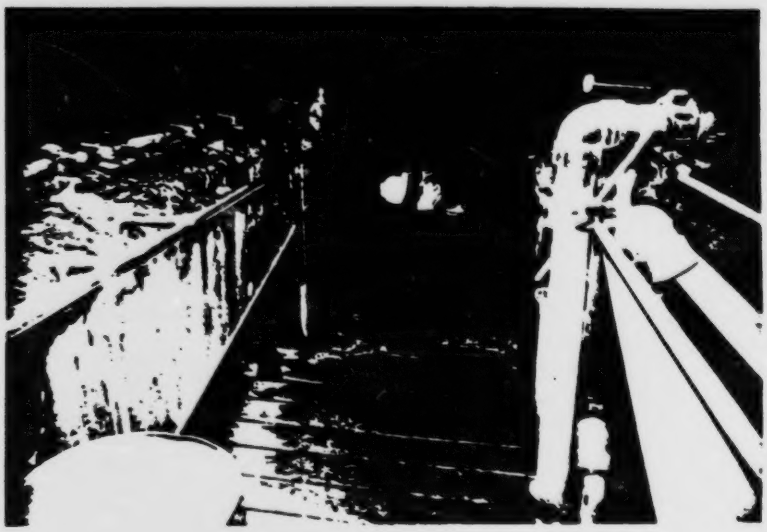


Figure 3.27b ZINC FLOTATION AREA

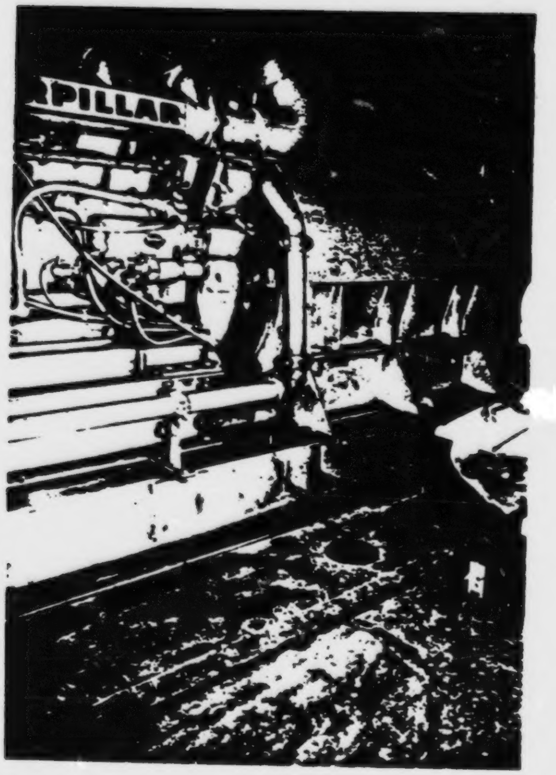


Figure 3.28a DIESEL ENGINE IN COMPRESSOR ROOM

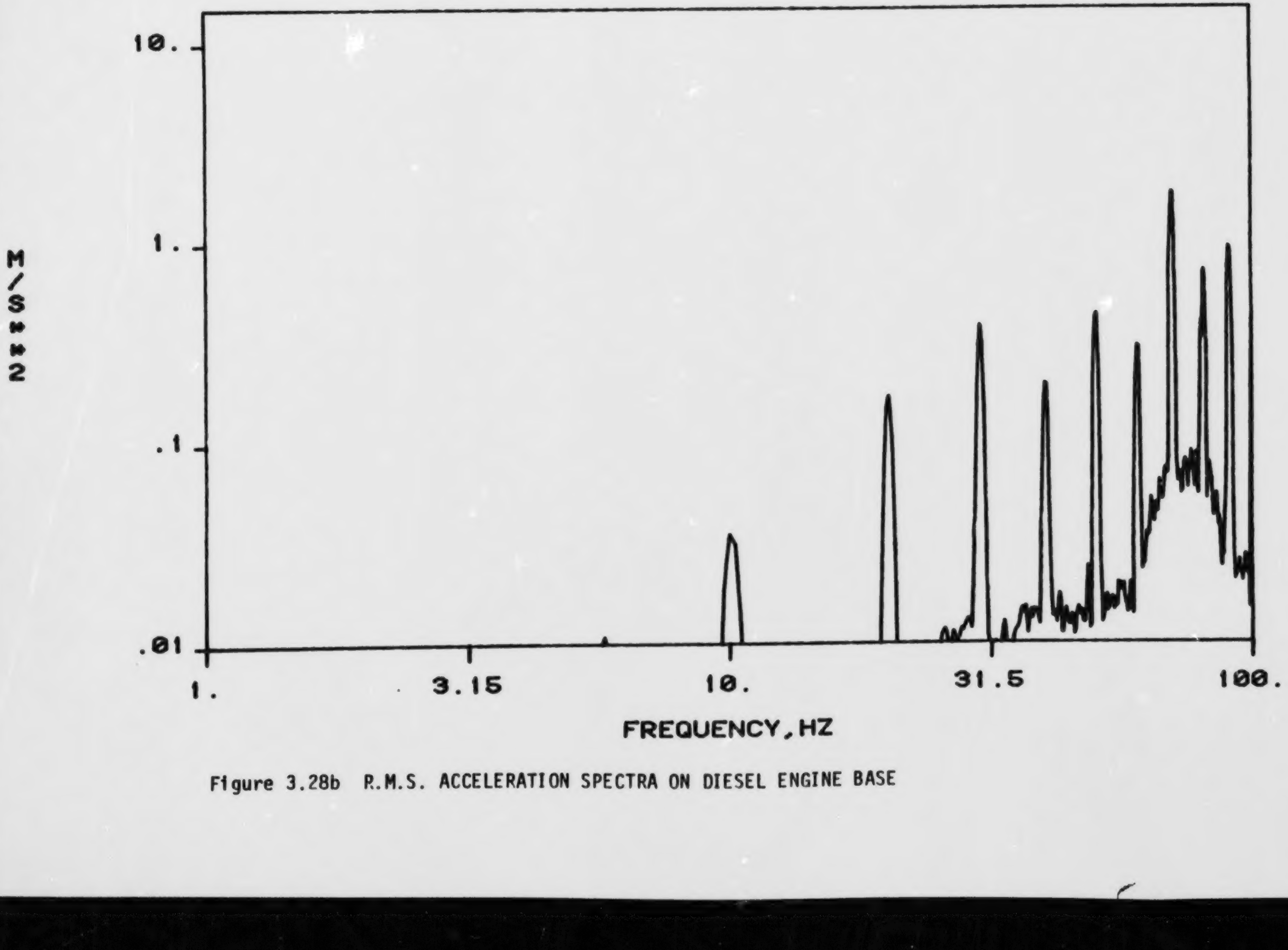


Figure 3.28b R.M.S. ACCELERATION SPECTRA ON DIESEL ENGINE BASE

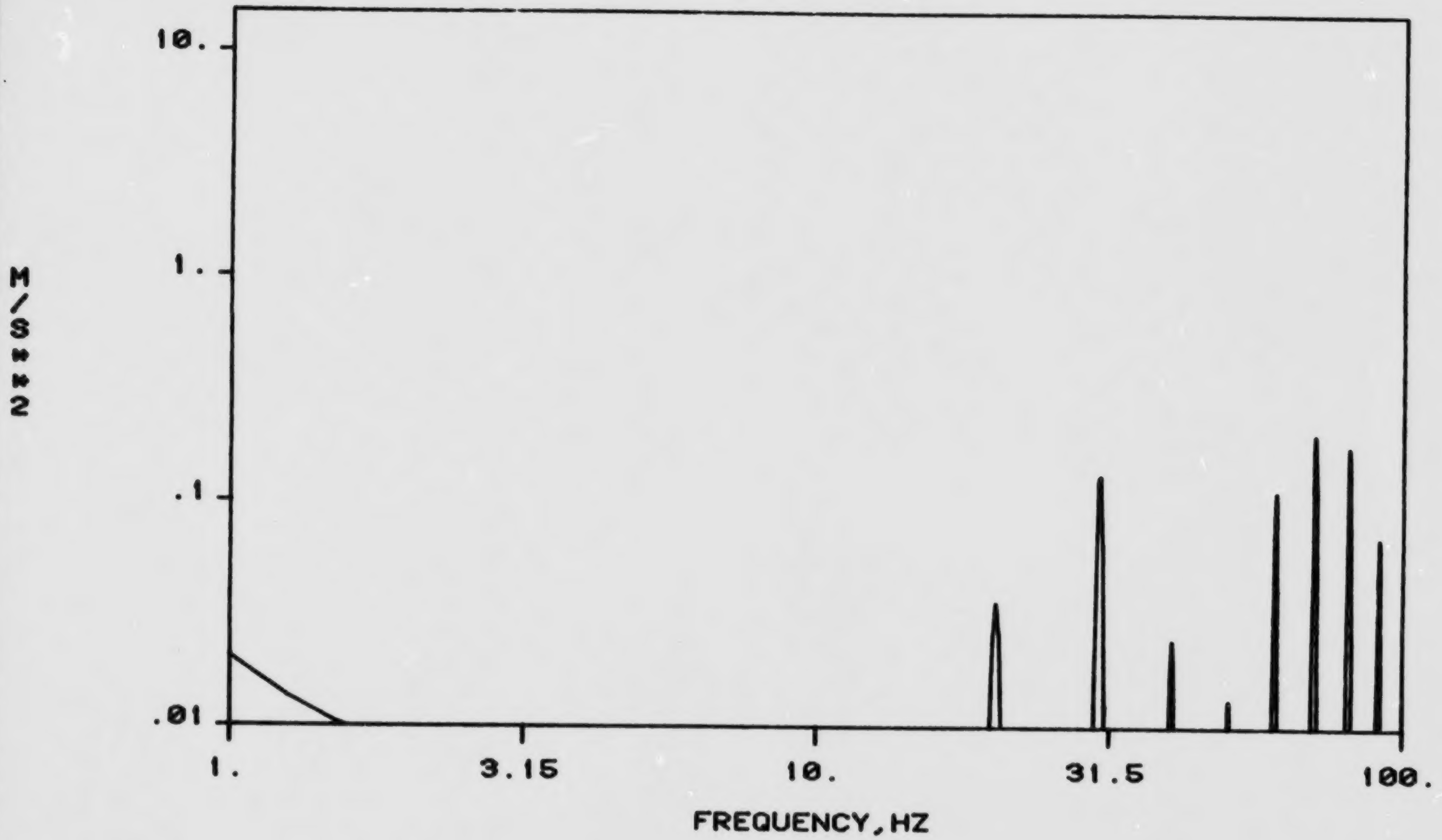


Figure 3.28c R.M.S. ACCELERATION SPECTRA ON ISOLATED FOUNDATION

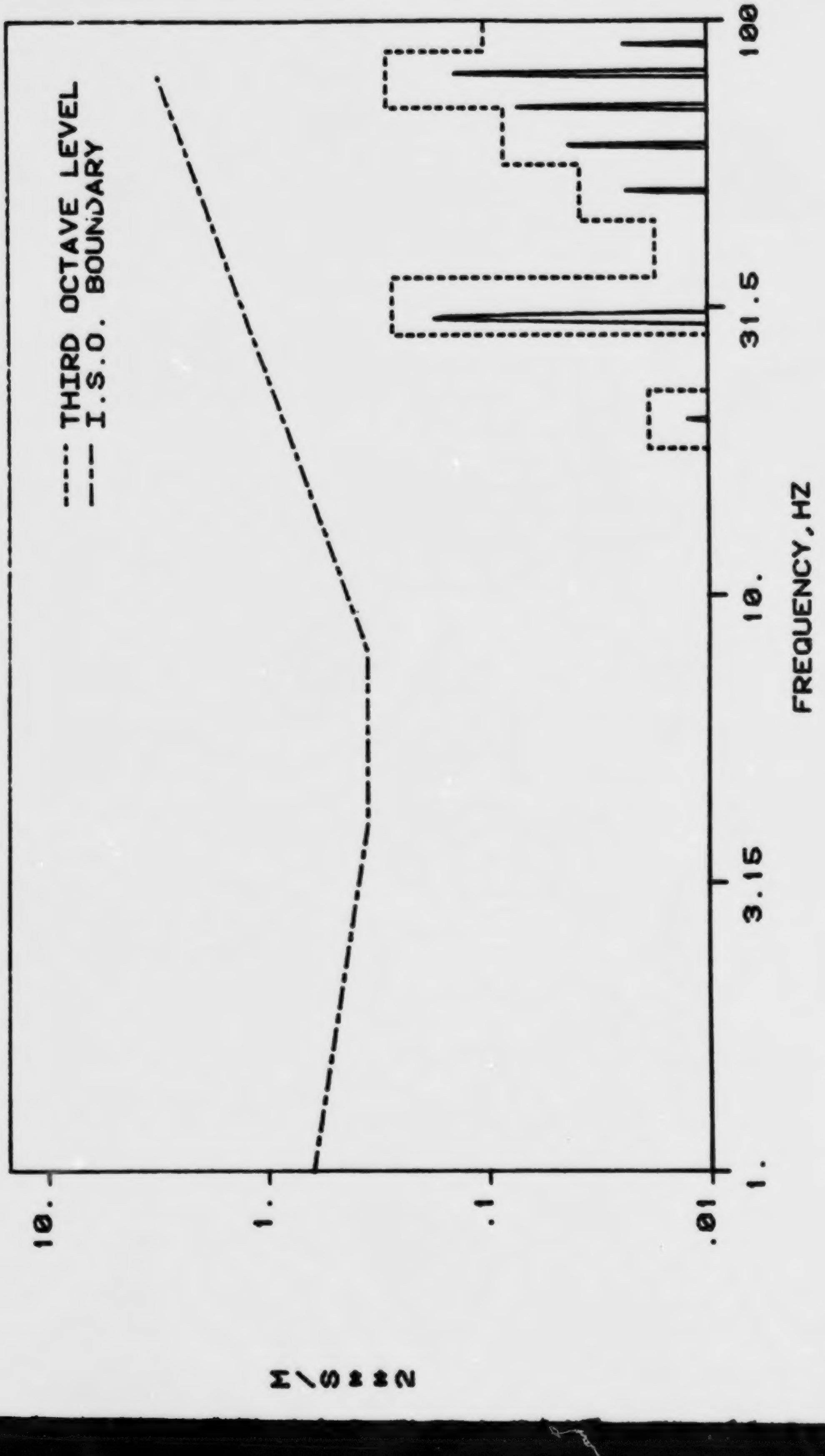


Figure 3.28d R.M.S. ACCELERATION SPECTRA ON CONCRETE FLOOR

3.7 Conclusions

Tests have been conducted on jack leg and stoper drills that provide much needed data on the vibration characteristics of these drills, and the influence of various operating parameters. Results taken for a single drill have been found to be highly repeatable and averaged spectra for both jack leg and stoper drills have demonstrated the existence of a well defined vibration spectrum for each drill. The effect of steel length and air pressure variations was not found to have a measurable effect on the vibration levels produced. The support condition, either timber or rock, was noted to have a marked effect on the vibration level of stoper drills.

The field results obtained have been analysed according to ISO DIS 5349 and the time taken for the onset of VWFD symptoms has been predicted. All the jack leg results obtained had approximately the same weighted acceleration level of close to 20 m/s^2 (for a 1.5 hours exposure time) which was the same as the average of all the stopers tested at the Westmin mine, whereas average levels of 32 m/s^2 were recorded at the Kimberly mine for some stopers. These results indicate that that the stoper produces vibrations that are likely to be more harmful than the jack leg. However as a stoper miner often holds the hose (which had a weighted acceleration level of 15 m/s^2) he may in fact take more time to develop VWFD symptoms.

Whole body vibration readings were recorded in the refiner and compressor room areas and locations were found where the vibration levels would, according to ISO 2631, give rise to reduced worker proficiency for an exposure period of eight hours.

4. LABORATORY TESTS

4.1 Introduction

In this portion of the study laboratory tests were conducted at the University of British Columbia to investigate the possibility of reducing vibration levels by of rock drills using relatively simple procedures that did not entail redesign of the drill firing mechanism.

Tests were conducted on a jack leg drill. The test configurations used were designed to check the effectiveness of the concept under evaluation and were not intended to be prototype developments.

Vibration measurements were taken by recording acceleration levels from accelerometers (Bruel and Kjaer 4332, 4375, 4370, 4336, 4344) attached to the drill via a mechanical filter (Bruel and Kjaer UA 0559) which was required in order to prevent excessive shock levels from damaging the accelerometer. The output from the accelerometer was amplified (Bruel and Kjaer 2635 and Kistler 504A) and stored on a FM tape recorder (Bruel and Kjaer 7003). A reference signal was provided by an accelerometer calibrator (Bruel and Kjaer 4291). Interpretation and analysis of the data was accomplished using a Nicolet 660A spectrum analyzer.

The experimental work conducted was designed to

(i) investigate the possibility of reducing the vibrations levels transmitted to the handle of the drill by the use of vibration absorption and vibration isolation techniques; and

(ii) evaluate the effectiveness for rock drilling of a hand held mount designed by Bruel and Kjaer for specific use in measuring the level of vibration transmitted to the hand. The need for such a mount arises from the fact that vibration levels measured on the handle of the drill may overestimate the levels transmitted into the hand. The investigation into the use of absorbers and isolators was motivated by a desire to seek a means of reducing vibration levels transmitted to the operator without a major redesign of the drill itself.

4.2 Testing of a Vibration Absorber

If acceleration levels are recorded on the handle of the air leg drill in the direction of drilling and the frequency spectrum of these accelerations is evaluated the results will typically appear as shown in Figure 4.1. As may be seen a dominating influence occurs at the firing frequency F_0 of the drill. Such an observation leads to a first order approximation of the disturbing forces that give rise to the vibrational response as a harmonic force with frequency F_0. Further, simplifying the drill and its air leg by a spring mass representation then the system may be represented as shown in Figure 4.2b where k_L represents the stiffness of the air leg in the Z (drilling) direction, m_D represents the mass of the drill, and $P \sin 2\pi F_0 t$ represents the excitation applied to the drill where F_0 = blow rate in Hz. Assuming such a representation, then as is well known in vibration theory [2] the addition of a vibration absorber of mass m_A and stiffness k_A where $\sqrt{k_A/m_A} = 2\pi F_0$ will give rise to a reduction in the response of the drill x_D at frequency F_0. The idealized drill

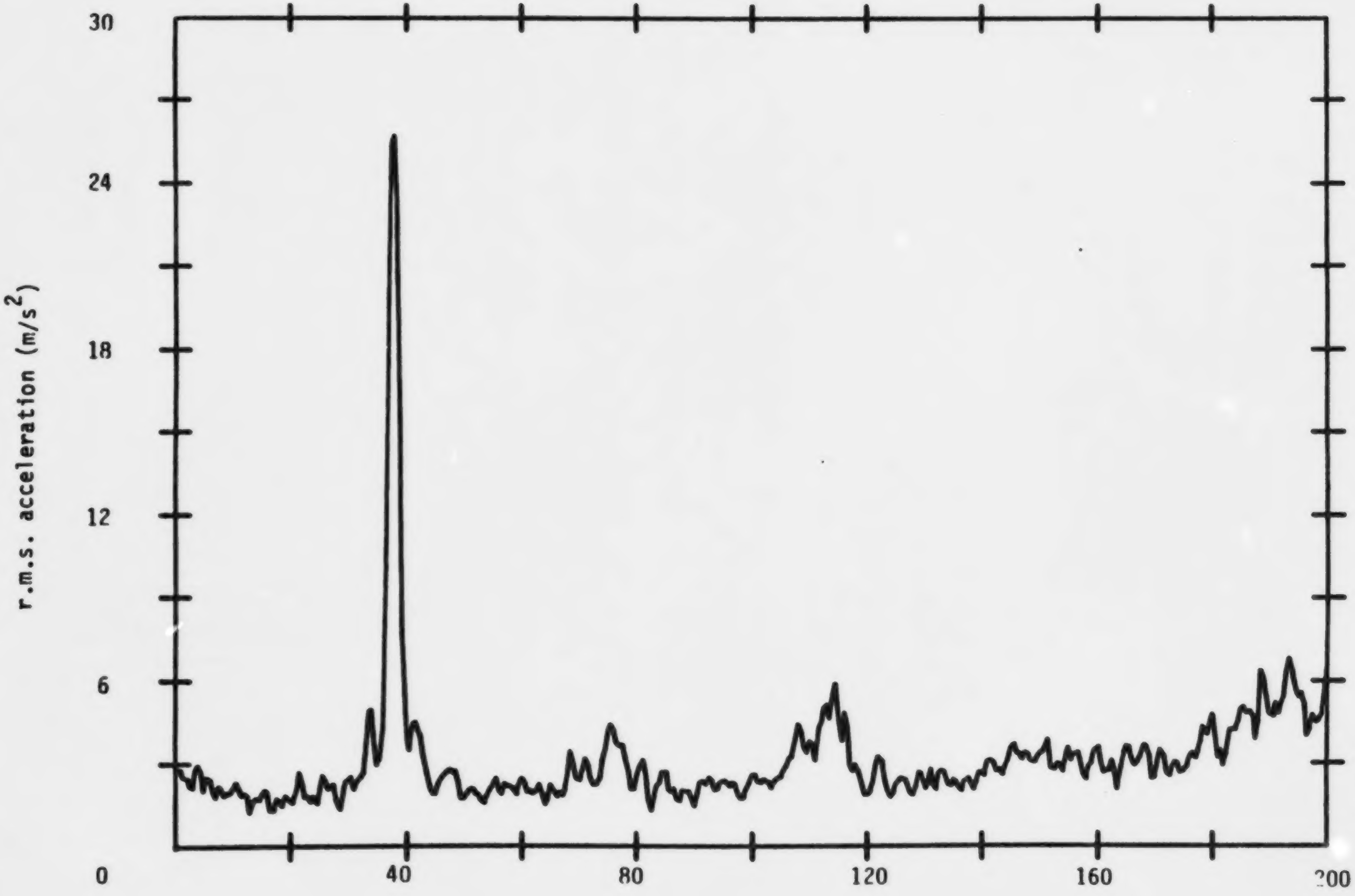
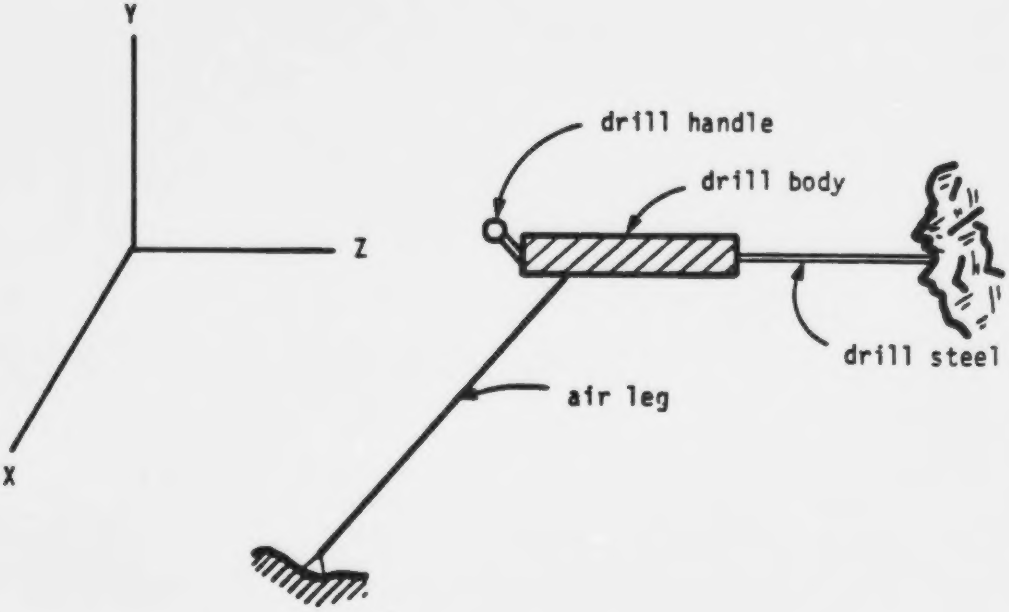
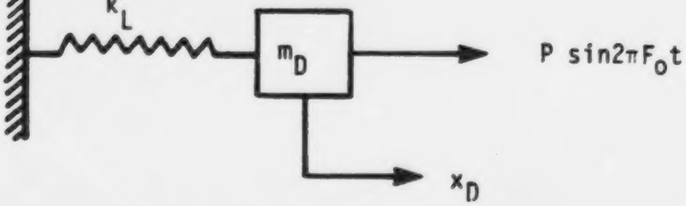


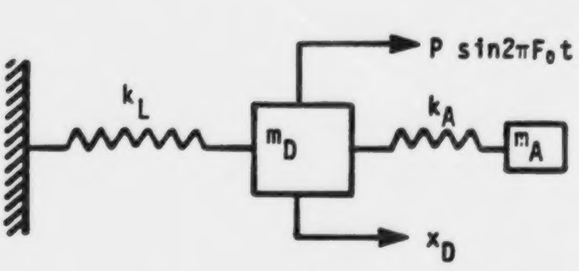
Figure 4.1 ACCELERATION SPECTRUM AT HANDLE OF JACK LEG DRILL


Y
Z
X
drill handle
drill body
drill steel
air leg

a) Air leg drill


k_L
m_D
$P \sin 2\pi F_0 t$
x_D

b) Idealization of drill and drilling forces


$P \sin 2\pi F_0 t$
k_L
m_D
k_A
m_A
x_D

c) Idealized system with vibration absorber

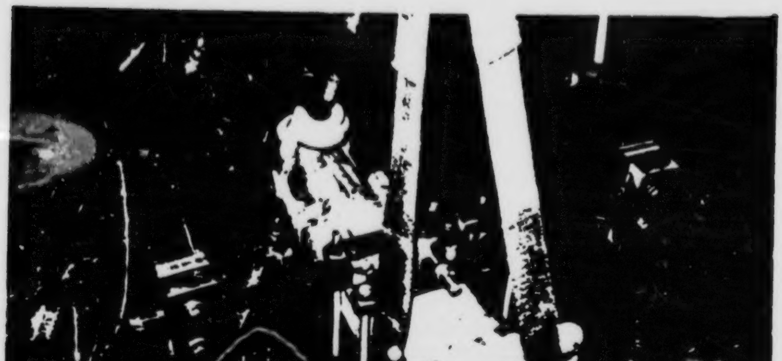
Figure 4.2 IDEALIZED REPRESENTATION OF DRILL AND ABSORBER

plus absorber is shown in Figure 4.2c. Clearly this model is a gross simplification of the actual system. However the possibility of reducing the vibration level at the blow rate F_0 by such a simple device was sufficiently attractive to pursue this alternative.

In order to test the effectiveness of the concept an absorber was constructed that could be attached to the handle of the drill and consisted of two 5lb weights which could be positioned on cantilevered 1" x 3/8" bars acting as springs. The frequency of the absorber could be tuned by moving the weights, and the whole arrangement was rigidly clamped to the handle of the drill. Initial testing using mild steel bars resulted in failure of the cantilevered arms at the root. Subsequent testing was conducted with 4140 Chrome alloy steel with a yield point of 180,000 psi, and an ultimate strength of 200,000 psi.

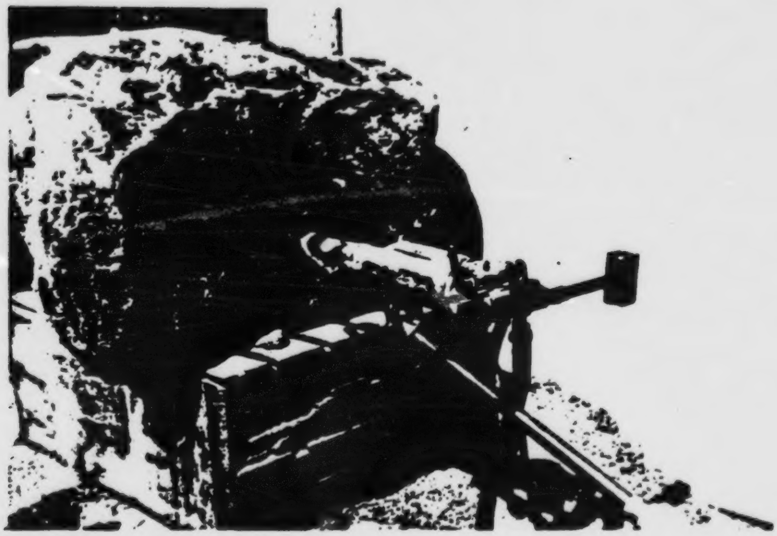
Tests were carried out both with the drill idling (see Figure 4.3) and during drilling (see Figure 4.4) into granite rock. The test results obtained during idling at part and full throttle are shown in Figure 4.5. In this figure the RMS cceleration levels at the blow rate frequency F_0 and twice the blow rate frequence $2F_0$ are compared for the drill with and without the absorber. These results were obtained by running the drill with and without the absorber and recording the spectrum (averaged over 32 records) and then comparing the spectrum levels obtained at F_0 and $2F_0$. Such readings were taken for different natural frequencies of the absorber (the natural frequencies of the absorber were found by impacting the absorber when attached to the drill handle.) As may be seen from the figure the results obtained at $2F_0$ show no significant difference whether the absorber is attached or not. This is as would be expected as the

(a) Absorber connected to drill handle.



(b) Absorber connected to drill body.

Figure 4.3 IDLING TESTS OF VIBRATION ABSORBER



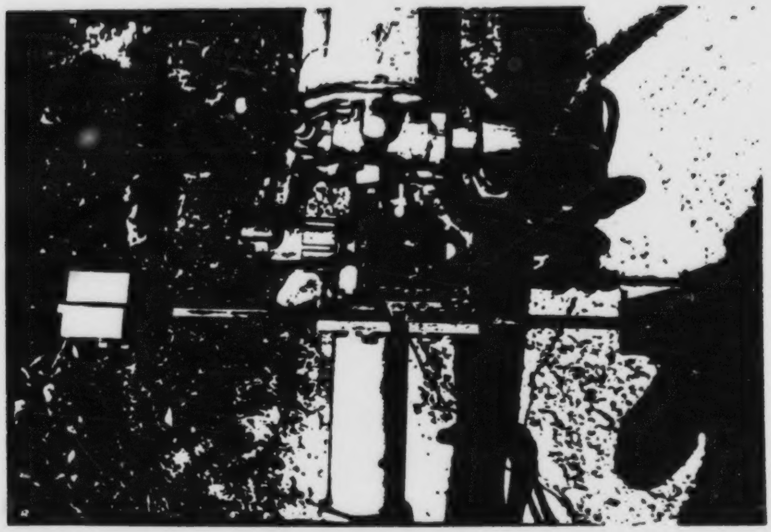


Figure 4.4 DRILLING TESTS OF VIBRATION ABSORBER

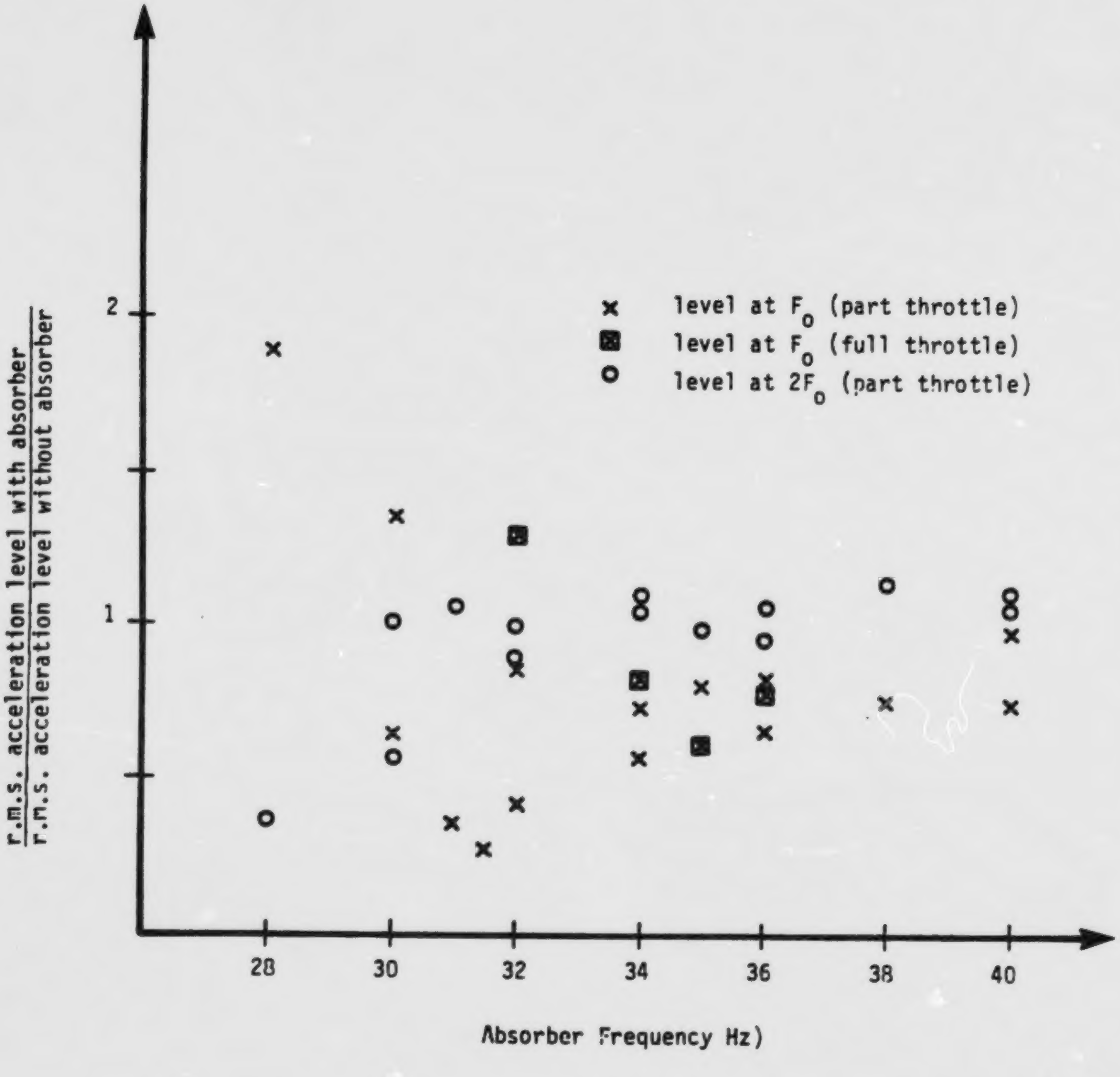


Figure 4.5 EFFECT OF VIBRATION ABSORBER ON IDLING DRILL

absorber is tuned basically to F_0. At F_0 it may be seen that attenuation of the vibration level is obtained in the range 34-36 Hz, although there is significant scatter to the results especially outside this frequency band. In these tests the firing frequency of the drill was approximately 33Hz.

Test results obtained during actual drilling at full throttle are shown in Figure 4.6. These results indicate no significant attenuation of vibration levels for a range of absorber frequencies around the blow rate of 33 Hz. The scatter of the results shown in Figure 4.6 is of the same order as is found between drilling tests conducted under the same nominal conditions.

As significant reductions in vibration levels are required at F_0 in order to satisfy ISO standards it was decided not to pursue, at this stage, further testing of the vibration absorber concept.

Tests were also conducted, during idling, with the absorber attached to the body of the drill (see Figure 4.3b). Again no significant vibration reduction occurred.

4.3 Testing of a Vibration Isolator

As an alternative to the vibration absorber concept, in which an attempt is made to balance the disturbing forces by a secondary system (the absorber) which itself undergoes significant vibrations, is the concept of vibration isolation. In this case an attempt is made to configure the dynamic characteristics of the system such that vibration is isolated from a particular area. In the case of the rock drill, isolation theory indicates that if the handle of the drill were designed to have a fundamental frequency significantly below the

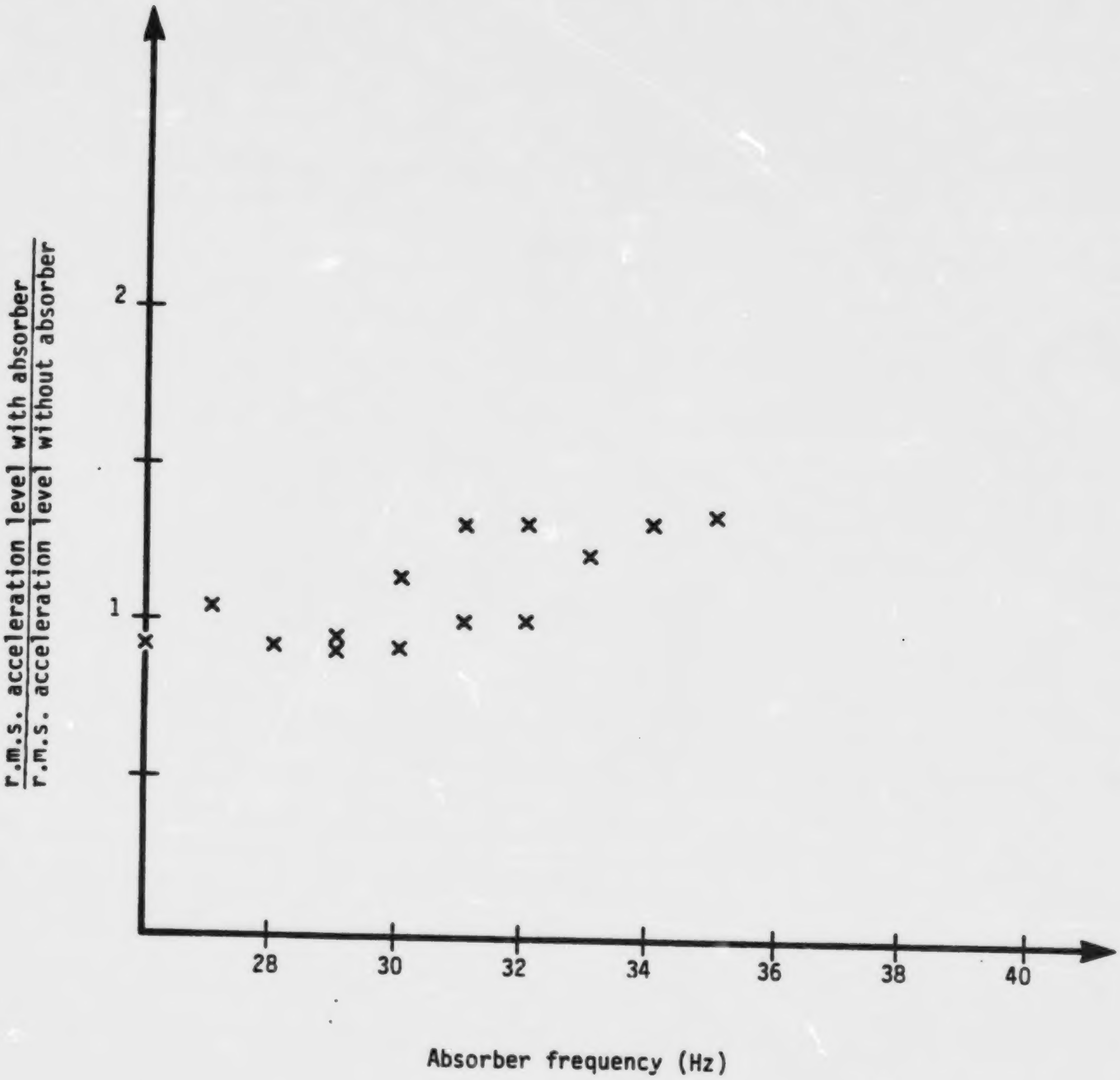


Figure 4.6 EFFECT OF VIBRATION ABSORBER DURING DRILLING

firing frequency (and with no other natural frequencies in the region of this frequency) then the energy at this frequency would be effectively isolated from the handle. In order to investigate this concept a "secondary" handle was designed as shown in Figure 4.7. This secondary handle was attached to the drill handle and serves to test the effectiveness of the concept of modifying the frequencies of the handle. The length L detailed in Figure 4.7 was adjustable in order that the frequency characteristics of the isolator could be varied.

As the primary frequency of the excitation for the drill was known to be approximately 33 Hz, the isolator was designed to have a fundamental frequency of the order of 10 Hz in the Z (drilling) direction. It was also recognized that if any of the natural frequencies of the isolator coincided with any of the major excitation frequencies of the drill then undesirable resonances would be induced. Although no attempt was made in the laboratory tests to design a practical handle it is recognized that the low flexibility associated with a low frequency handle may not be tolerable in the field. It is envisaged that the required stiffness may be achieved by the use of suitably designed rigid stops. In order to test the concept in the laboratory the drill and the attached isolator were suspended from a cradle and the drill run at full throttle for a short time. Acceleration levels were measured simultaneously on the isolator and the drill handle. To investigate the effect of changing the fundamental frequency of the isolator the length L (see Figure 4.7) was varied. The natural frequencies of the isolator were determined by impact testing and are summarized in Table 4.1. In the Z direction the lowest frequency corresponds to the mode where both

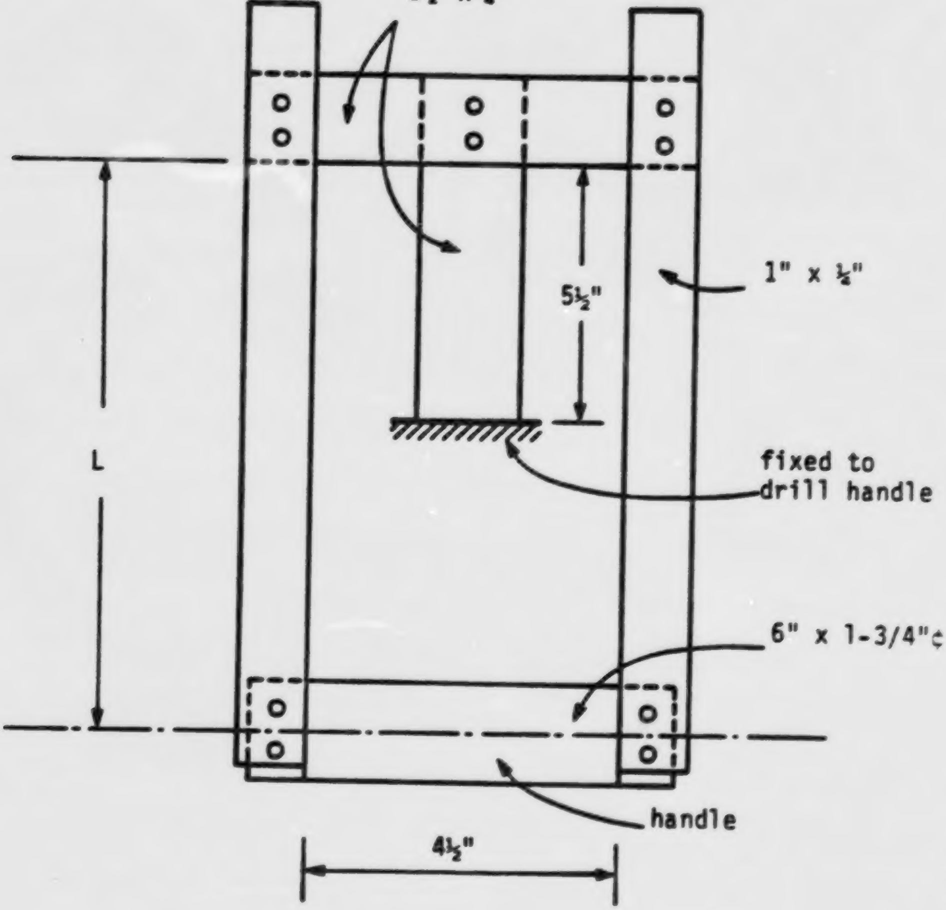

1½" x ¼"
1" x ½"
5½"
L
fixed to
drill handle
6" x 1-3/4"¢
handle
4½"

Figure 4.7 DETAILS OF VIBRATION ISOLATOR

TABLE 4.1 NATURAL FREQUENCIES OF ISOLATOR (Hz)

L	Z Direction		Y Direction		
9 3/4"	17	64	25	32	38
11 3/4"	12	54	25	33	38
13 3/4"	10	49	26	33	38

support arms for the isolator handle moved in phase, whereas the second frequency corresponded to the mode where the arms moved out of phase i.e. the mode corresponded to a twisting about the Y axis. As may be noted the natural frequencies in the Y direction are close to the firing frequency and hence amplification may be expected in this direction.

In Figures 4.8 and 4.9 a comparison is presented of the RMS acceleration responses measured on the drill and isolator handles in both the Z and Y directions for the case when L = 13-3/4". In Table 4.2 the acceleration levels recorded at frequencies F_0 and $2F_0$ for the three different configurations of the isolator are given. As may be noted significant reductions in vibration levels were obtained in the Z direction at both F_0 and $2F_0$. In the Y direction no such significant reduction occurred as may be anticipated as there did not exist any low frequency coupling between the drill and isolator handle

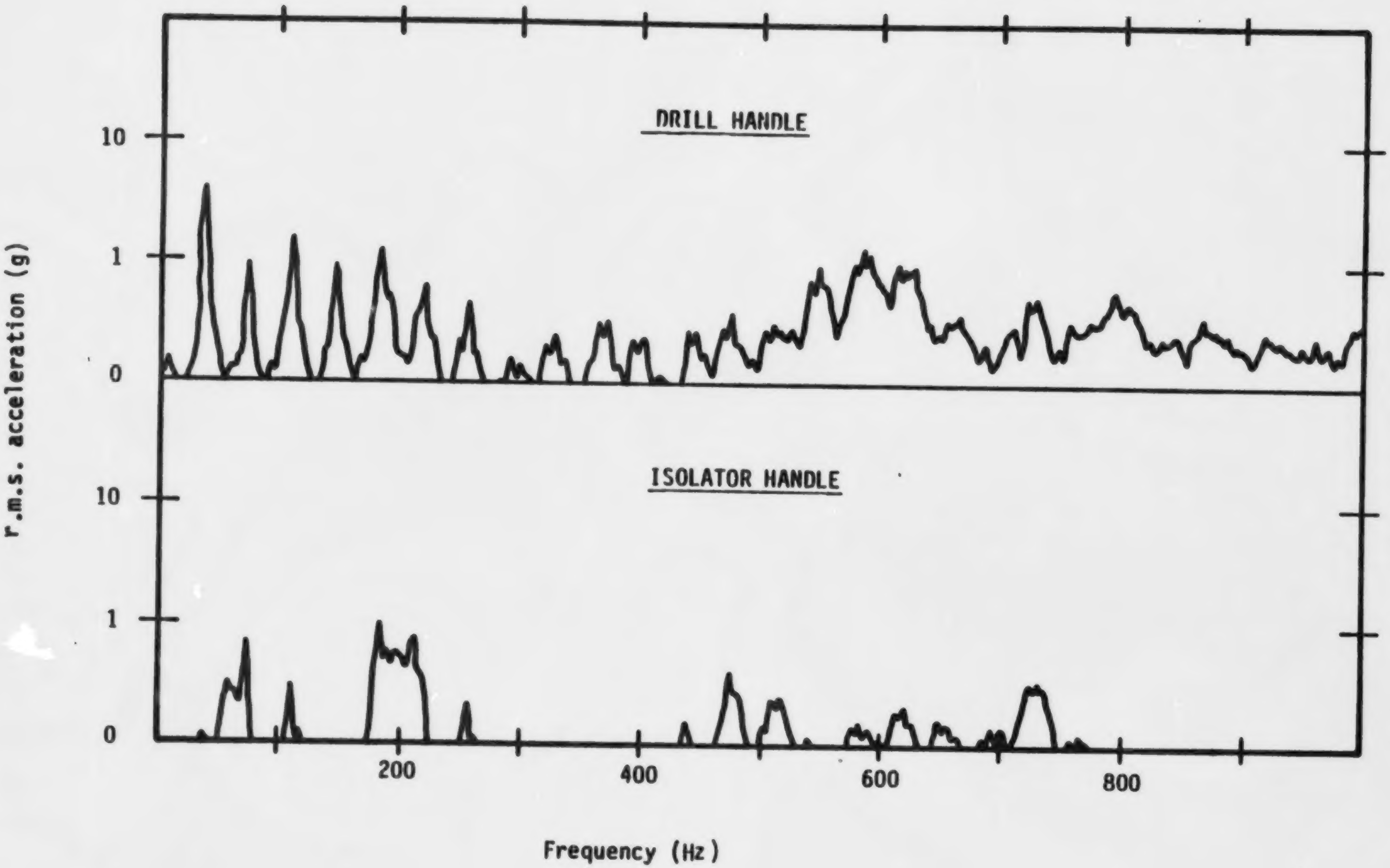


Figure 4.8 EFFECT OF ISOLATER ON R.M.S. ACCELERATIONS IN Z-DIRECTION

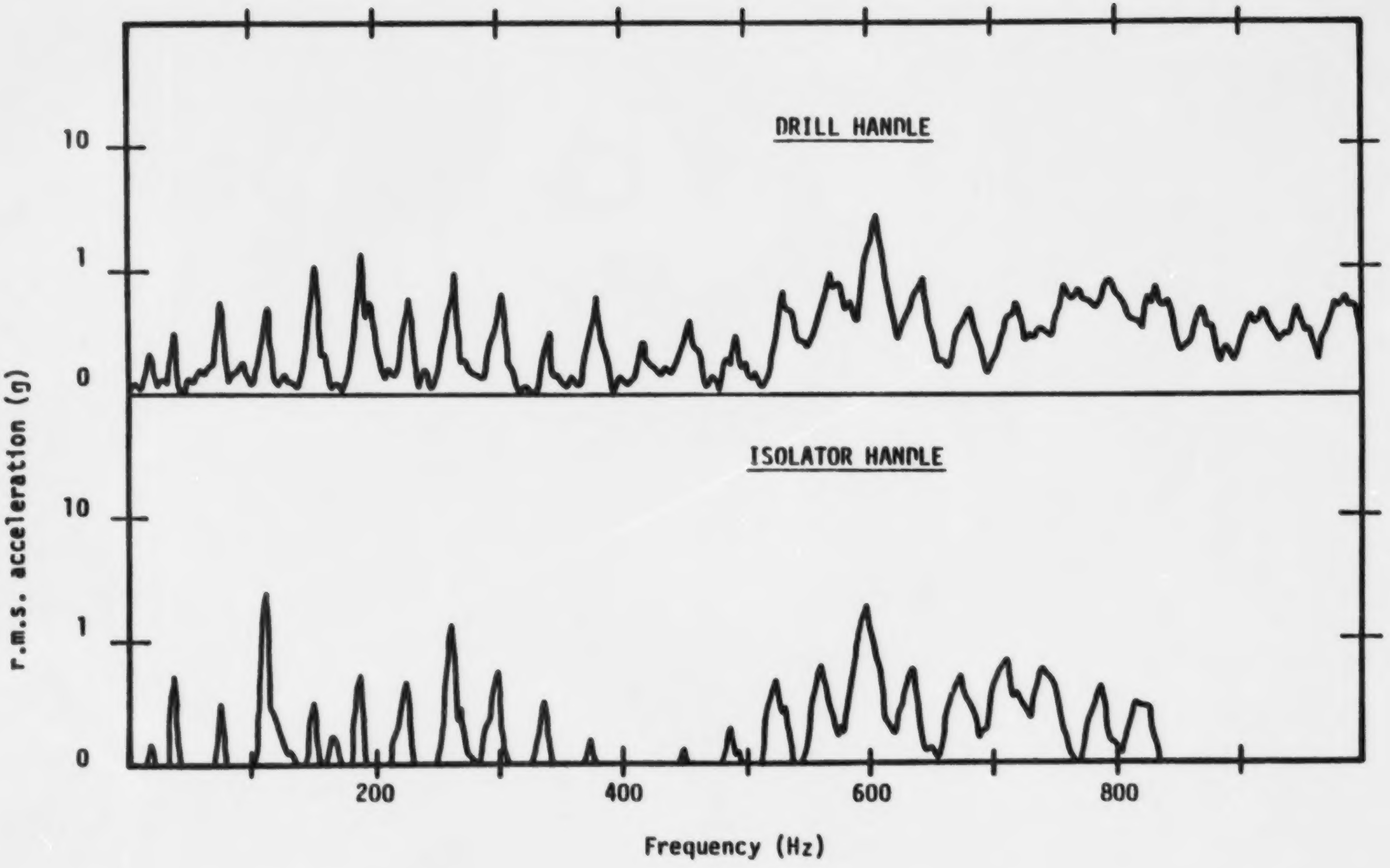


Figure 4.9 EFFECT OF ISOLATOR ON R.M.S. ACCELERATION IN Y-DIRECTION

TABLE 4.2 COMPARISON OF ACCELERATION LEVELS (m/s²) BETWEEN DRILL AND ISOLATOR HANDLE [IDLING TESTS]

	Z Direction		Y Direction	
	F_0	$2F_0$	F_0	$2F_0$
Drill Handle	44	23	5	14
Isolator Handle				
L = 9 3/4"	17	5	3	1
L = 11 3/4"	2	4	5	5
L = 13 3/4"	2	4	5	11

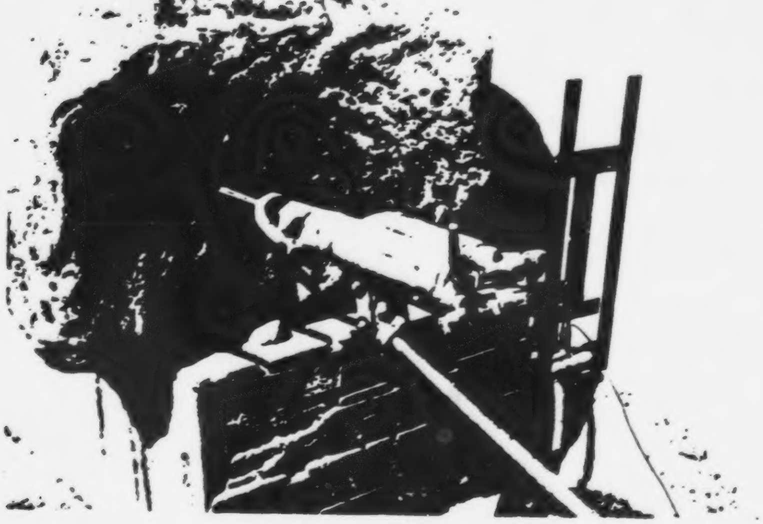
Table 4.3 COMPARISON OF ACCELERATION LEVELS (m/s²) BETWEEN DRILL AND ISOLATOR HANDLE

Drill Handle	27	26	23
Isolator Handle	3	3	4

in the Y direction. In fact the isolators had natural frequencies in the Y direction close to the firing frequency of 33 Hz which explains why in some tests amplification of the vibrations occurred in the Y direction. A series of tests were conducted to evaluate the performance of the isolator during drilling conditions (see Figure 4.10). Table 4.3 shows a comparison of the acceleration levels measured on the drill handle with those measured on the isolator handle. These results were recorded at the firing frequency F_0 = 33 Hz and the isolator had a fundamental frequency of 12 Hz. As may be noted in two of the three tests the levels were reduced by a factor of 10.

The results obtained in the Y direction gave an amplification of the acceleration levels by a factor of approximately three. As has been mentioned this was probably caused by a natural frequency in the Y direction close to the firing frequency. Further testing would be desirable in order to modify the isolator's dynamic characteristics in the Y direction to eliminate this problem.

The test results presented indicate that if service requirements with regard to handle flexibility can be met then a suitably designed drill handle may well reduce the vibration levels by an extent that would be significant in terms of delaying the onset of VWFD symptoms.



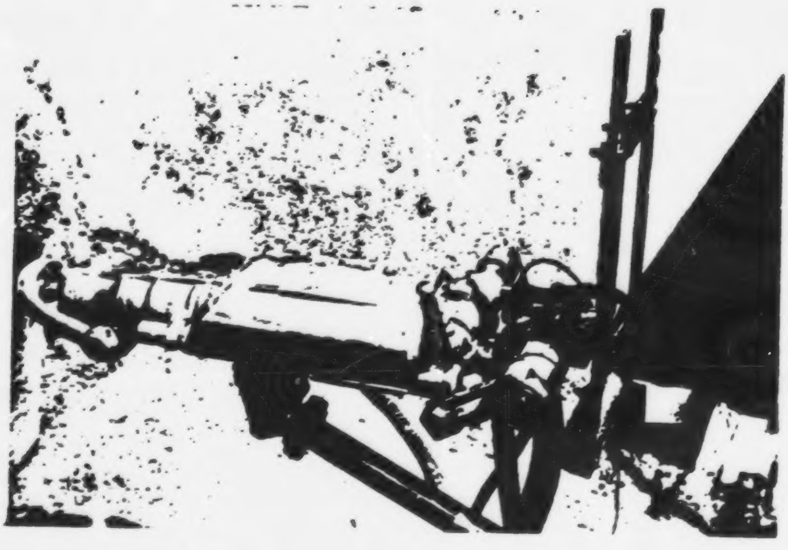


Figure 4.10 DRILLING TESTS OF THE VIBRATION ISOLATOR

4.4 Laboratory Testing of Hand-Held Vibration Mount

In evaluating the effects of vibration transmitted through the hand ISO 5349 "Principles for the Measurement and Evaluation of Human Exposure to Vibration Transmitted to the Hand" is often used as the relevant standard. In the latest version this standard it is prescribed that vibration levels should be measured on the handle of the drill. In order to attempt to measure more accurately the vibration levels transmitted into the hand the instrument manufacturer Bruel and Kjaer have developed the hand held vibration mount shown in Figure 4.11. The base of the mount is held by the drill operator against the handle of the drill and the location of the accelerometers has been designed to correspond closely with that specified by previous versions of ISO 5349. The mount has been designed to accept three miniature accelerometers in three orthogonal directions although it may be noted that supporting field instrumentation, namely Bruel and Kjaer 2513 Integrating kibration Meter, is only able to process data from one channel at a time. The 2513 Integrating Vibration Meter outputs 1 minute averages of the recorded vibration levels to a C101 data storer which has sufficient memory to store data for up to 25 hours. The 2513 and C101 may be enclosed in a protective box and attached to the operator, as shown in Figure 4.12. The operator can then, at least in theory, collect data that will represent his vibration exposure for the period of his shift. At the end of the shift the data may be output to a Bruel and Kjaer Alpha numeric Printer type 2312 which provides a hard copy record of the vibration levels. In practice the mount and trailing cables are not appropriate for general use in a mine. Attempts were made to use this set up in the underground tests conducted at the Westmin mine. However problems

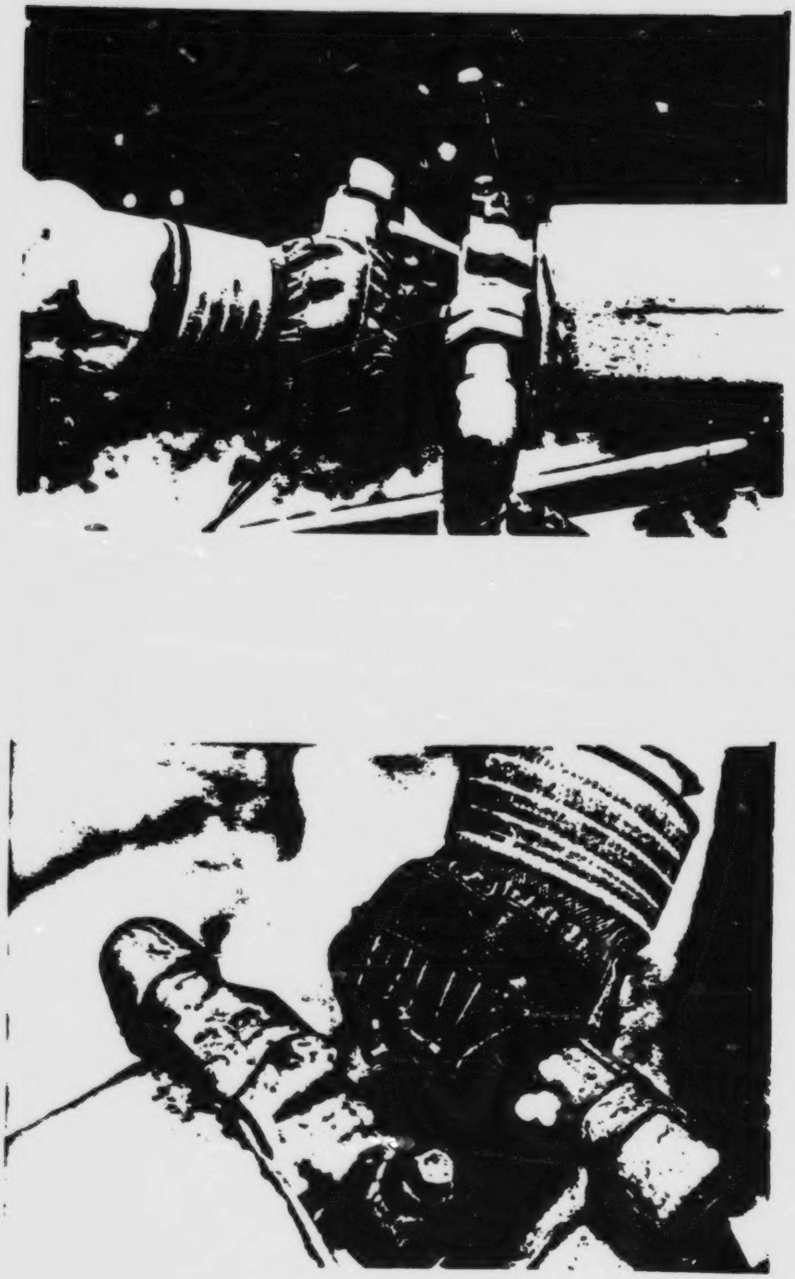


Figure 4.11 HAND HELD VIBRATION MOUNT

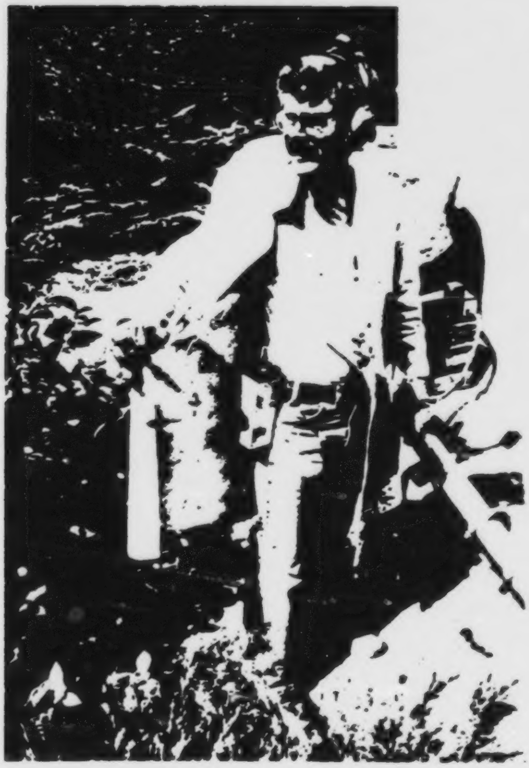


Figure 4.12 HAND HELD MOUNT CONNECTED TO VIBRATION METER AND DATA STORER ENCLOSED IN PROTECTIVE CASING

with the instrumentation prevented readings from being taken. Further, the mount is not appropriate for use in its present form except for a well controlled test run. For general monitoring purposes all attachments must be more ruggedly designed. It is conceivable that attaching the 2513 and C101 in a protected casing attached to the drill, and then attaching the accelerometer directly to the handle in another protective casing with a steel hose connecting the two may constitute a practical way of obtaining exposure readings for a complete shift.

Drilling tests were conducted with the mount to (i) compare acceleration levels obtained on the drill handle with those obtained on the mount and (ii) to simultaneously measure the XYZ components recorded on the mount.

In Table 4.4 the RMS acceleration levels obtained on the handle and on the mount are compared. These results indicate (as did subsequent tests) that levels recorded in the Z direction were very much the same on the handle as on the mount but that in the X and Y directions the levels recorded at the mount were significantly higher than those recorded on the handle. These results were obtained with the operator of the drill holding the mount against the drill handle. However if the mount were rigidly clamped to the handle the readings in all three directions were comparable.

A further test was conducted in which accelerations were recorded simultaneously in the X Y and Z directions. These results are presented in Table 4.5. Once again it is observed that the Y and X levels are relatively high compared to the results obtained on the drill handle.

It would appear from the results obtained that the usual

TABLE 4.4 COMPARISON OF HANDLE AND MOUNT RMS ACCELERATION LEVELS(m/s^2)

Direction		X	Y		Z	
Handle:	F_0	3	4	7	19	20
	$2F_0$	1	5	2	6	9
Mount:	F_0	6	17	9	18	15
	$2F_0$	9	2	4	12	7

TABLE 4.5 RMS ACCELERATION LEVELS (m/s^2) AT MOUNT IN X, Y, Z DIRECTIONS

Direction	X					Y					Z				
F_0	4	4	4	1	2	19	7	14	14	14	10	9	9	11	11
$2F_0$	2	2	4	1	2	10	4	9	8	12	3	2	4	3	4

assumption that the acceleration level in the Z direction is the highest [as it is at the handle] is not necessarily true at the location of the mount. Thus using the mount to obtain uniaxial readings in the Z direction may give an erroneous picture of the maximum acceleration level at the location of the mount. In order to define the exact vibration level requires therefore, that simultaneous readings be taken in three orthogonal directions. At the present time the instrumentation available to do this is not well suited to obtaining results in a mine environment. A further complication in using the mount to obtain uniaxial measurements arises from the fact that a drill operator rarely keeps his hand oriented in a fixed direction during drilling, whence the readings obtained from the mount correspond to accelerations in different and undefined directions.

Thus it may be seen that serious complications arise in attempting to measure appropriate vibration levels using the mount. A question that naturally arises is whether, given the unknowns of the problem and the inherent scatter of the data obtained, any real benefit is accrued by attempting to measure vibration levels at locations other than on the handle of the work piece; and indeed, the latest version of ISO 5349 (Revised Sept. 1982) specifies that measurements should be taken on the handle of the drill.

4.5 Conclusions

From the laboratory and drilling tests conducted it has been demonstrated that

(i) attaching a vibration isolator to the handle of an air leg rock drill can lead to significant reductions in the level of vibrations transmitted

(ii) attaching a vibration absorber to the drill did not result in significant reductions in vibration levels.

(iii) the hand held mount and corresponding instrumentation designed specifically for measuring hand held vibration is not well suited to the problem of obtaining vibration measurements in a mine.

The results obtained relating to the vibration isolator indicate that further work in this area would be desirable. Specifically it would be worthwhile to develop a handle designed itself to act as an isolator.

5. COMPUTER INTERFACING OF EXISTING VIBRATION INSTRUMENTATION

5.1 Introduction

The well known instrumentation manufacturer Bruel and Kjaer has developed specific instrumentation for the measurement and recording of vibration that extends over a prolonged period of time. This instrumentation, which is intended to be of particular use in the measurement and recording of hand-arm vibration, consists of a number of components:

(i) Integrating Vibration Meter Type 2513

This hand sized meter has a thermometer type display and records either vibration velocity or acceleration with a choice of RMS, max-RMS, peak and peak/60s L_{eq} indications. The meter incorporates an electronic weighting filter to permit measurements to be made in accordance to ISO Draft 5349, in this mode the instrument will produce each minute a d.c. pulse representative of the weighted acceleration level that can be stored on a data storer.

(ii) Data Storer Type C101

This is a battery powered unit, that can be attached to the 2513, capable of storing one minute averages passed from the 2513 for periods up to 25 hours.

(iii) Data Processor Type C102

The instrument is designed to read and manipulate data fed from the data storer type C101.

(iv) Alphanumeric Printer Type 2312

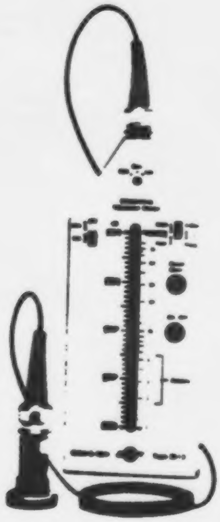
This is a low power battery operated alphanumeric printer which conforms to IEC 625-1 Interface Bus Standard and can be used to produce a hard copy record of the data in the C102 unit. In Figure 5.1 each of these instruments is illustrated and in Figure 5.2 a typical output from the Alphanumeric Printer Type 2312 is shown.

With the growing usage of computers it was felt that any instrumentation that stored considerable quantities of data would in the future need to be capable of interfacing to a computer in such a way that the data could be easily presented by graphical means and a convenient hard copy record be made readily available. To this end it was required as part of the contract to investigate the possibility of interfacing the existing Bruel and Kjaer instrumentation to a computer. It was suggested that initially the possibility of eliminating the 2312 printer should be investigated, however it was decided after an investigation of the problem that data could be transferred directly to a computer from the Data Storer Type C101. The interfacing that was done was to a PDP 11/34 as such a machine was available for this work, interfacing to other computers that have an RS 232 port will follow the same lines.

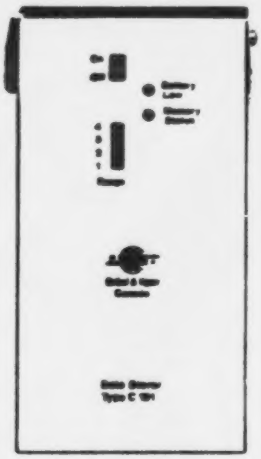
5.2 RS 232 Interface of a Bruel and Kjaer C101 Data Storer and a Computer

The Bruel and Kjaer C101 Data Storer is a portable analogue to digital converter for use with several Bruel and Kjaer sound level and vibration meters. The output from the meter is

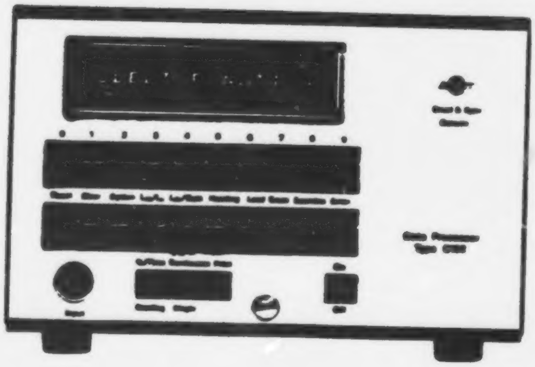
Integrating Vibration Meter Type 2513



Data Storer Type C 101



Data Processor Type C 102



Alphanumeric Printer Type 2312

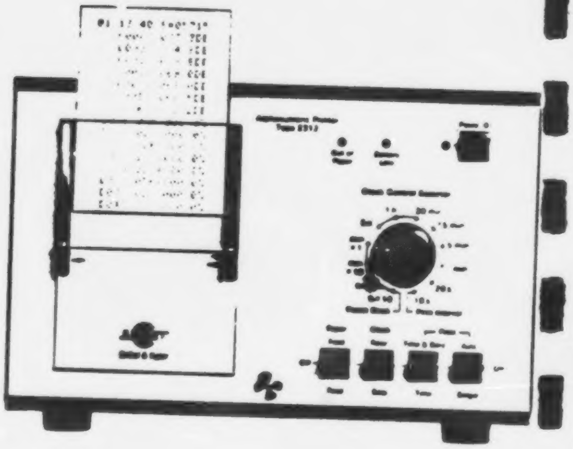


Figure 5.1 DATA COLLECTION AND RECORDING INSTRUMENTATION

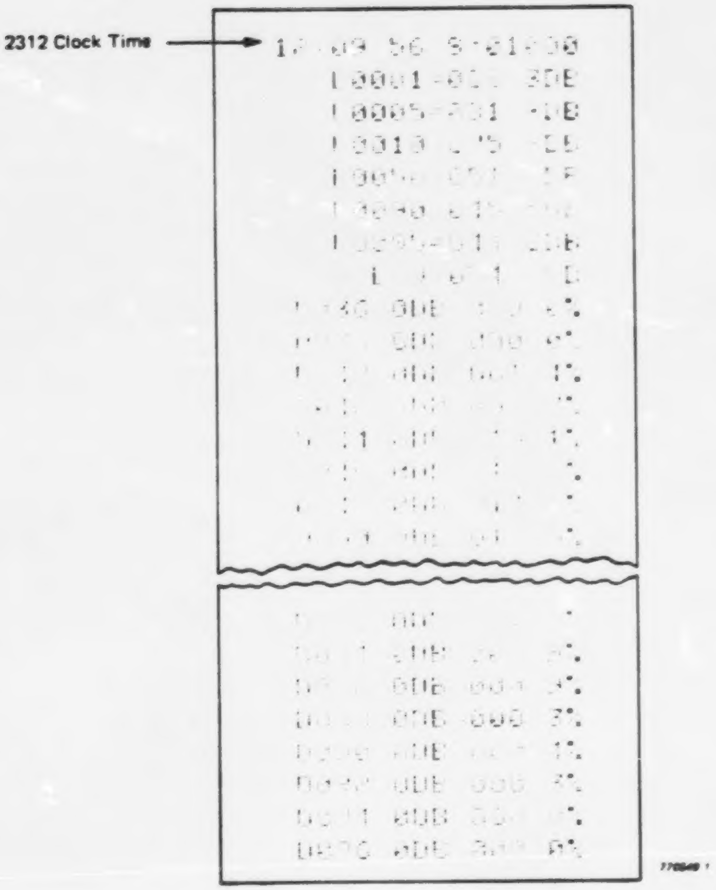

2312 Clock Time
770648 1

Figure 5.2 OUTPUT FROM PRINTER TYPE 2312

converted from a voltage to a digital number and stored in nonvolatile memory in the C101.

The problem of interfacing the C101 to the PDP 11/34 was divided into three parts: first it was necessary to understand the code used by the C101 to output its data; second it was necessary to design a hardware interface between the C101 and the PDP 11/34 and finally it was necessary to write a computer program to read and translate the data.

C101 Data Format

The C101 transmits all its data as ASCII characters. The first character is always a "?". This is always followed by a range specifier, that identifies the offset that must be added to the data to obtain the value read by the C101. The range specifiers are as follows: range "1" gives an offset of 20 dB, range "2" gives an offset of 50 dB, range "3" gives an offset of 80 dB and range "4" gives an offset of 100 dB. This combination of "?" and a range specifier is also used to separate the different files in the C101.

Each data point is output from the C101 as a pair of ASCII characters. To recreate the data point it is necessary to combine the pair of characters into one eight bit byte. This is done by discarding all but the four least significant bits of the two characters. This pair of four bit nibbles are then combined to make the eight bit byte, with the nibble from, the first character forming the most significant nibble of the data byte and the nibble from the second character forming the least significant nibble of the data byte. Bits 0 and 1 of this byte form the decimal part of the data value and bits 2 to 7 form the integer part of the data value. Figure 5.3 one shows how the bits are rearranged and give an example showing how to convert the character pair "7" and "4" to a data value. Once the data value has been extracted from the characters the range offset has to be added in to get the final number.

The end of the data is indicated by the C101 sending the character "X".

Hardware Interface:

Data is transferred from the C101 in the following manner. The terminal line on the C101 (pin 7) is normally low. The C101 is "armed" by bringing this line high. The send line (pin 4) is normally high. Data transfer is started by bringing this line low. When the send line is low data is transmitted on the data out line (pin 2).

The way this was implemented is as follows. The send line (pin 4), the digital ground (pin 8) and the transitor switch base input (pin 9) were wired together. The 6 volt supply line (pin 6) and the terminal line (pin 7) were wired together through a 1.1 K ohm resistor. The data output line (pin 2) of the C101 was connected to the data out line (pin 2) of an RS232C connector. Finally the ground line (pin 8) of the C101 was connected to the ground line (pin 7) of the RS232C connector. Figure 5.4 is a diagram of how the connections were made.

1st character 011 HGFE

2nd character 001 DCBA

Data Byte H G F E D C B A

integer decimal

Note: for B A = 00, then the decimal = 0.00

for B A = 01, then the decimal = 0.25

for B A = 10, then the decimal = 0.50

for B A = 11, then the decimal = 0.75

For example the character pair "7", "5" would be converted as follows:

ASCII "7" = Octal 67 = 011 0111

ASCII "5" = octal 64 = 011 0101

data byte = 0111 0101

Integer = 011101 = 29.

decimal = 01 = .25

29.25

Figure 5.3 CONVERSION OF A CHARACTER PAIR TO A DECIMAL NUMBER

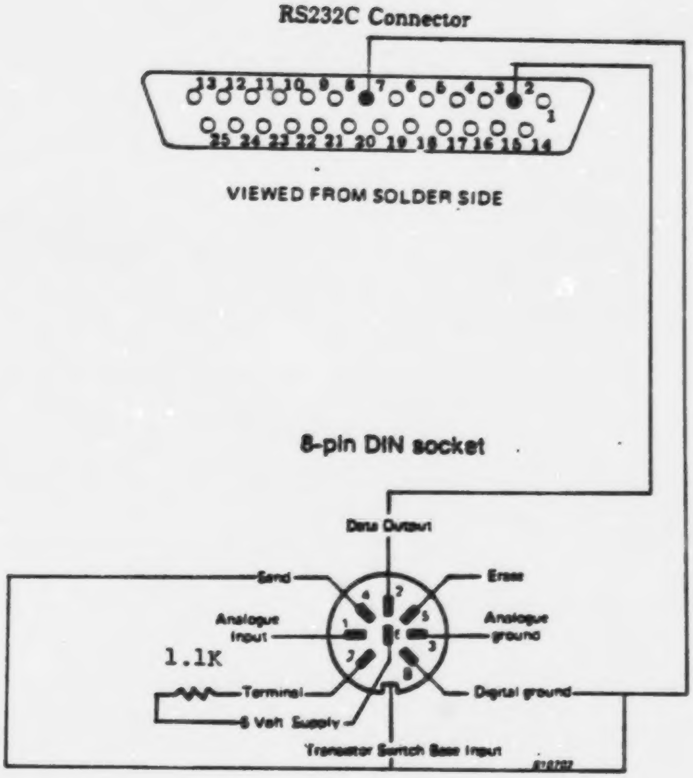

RS232C Connector
13 12 11 10 9 8 7 6 5 4 3 2 1
25 24 23 22 21 20 19 18 17 16 15 14
VIEWED FROM SOLDER SIDE
8-pin DIN socket
Data Output
Send
Erase
Analogue input
Analogue ground
1.1K
Terminal
5 Volt Supply
Digital ground
Transistor Switch Base Input

Figure 5.4 INPUT/OUTPUT SOCKET PIN CONNECTIONS SHOWN LOOKING INTO THE SOCKET

Computer Program

A listing for the computer program is given in the Appendix. The comments in the program should make it self explanatory. As it is written the program will only receive a maximum of 200 characters from the C101. This number may have to be increased. The amount of space necessary can be calculated as follows, each data point requires two characters, each file requires two characters and the end of data requires one character. The number calculated should replace the 200 in lines 3 and 15 of the program.

It should be noted that the C101 does not do any handshaking in either hardware or software, therefore it is necessary to run the program with a fairly high priority to insure that no data is lost. In our case we ran with a priority of 200.

5.3 Conclusions

With the development of a computer interface for the data storer not only are the data processor and the printer not required but the data manipulation and presentation possibilities, for the data stored in the C101, are only limited by the scope of software available for the computer. Thus in general, data manipulation, file storaage and graphical presentation can all be readily accomplished. Such an arrangement would be ideally suited to the needs of a mine requiring to make regular data checks and be able to quickly compare with previously obtained information.

6. REFERENCES

1. Hutton, S.G., and Brubaker, R., "The Effect of Vibration Upon Workers in the Mining Industry." Contract Report submitted to D.S.S. Energy Mines and Resources, 1980.

2. Den Hartog, J.P., Mechanical Vibrations, McGraw Hill Book Company.

7. APPENDIX

This appendix contains computer programs to:

- (i) Interface between a Bruel and Kjaer C101 data storer and a PDP 11/34 computer;
- (ii) Calculate 4 hour frequency-weighted acceleration level according to ISO DIS 5349 from data output from a Nicolet 660A spectrum analyzer; and
- (iii) Calculate third octave analysis of data output from a Nicolet 660A spectrum analyzer.

NOTE

These computer programs, in Fortran IV, have been omitted from this reprint because of their specificity and lack of general application.

If required, transcripts can be obtained from the Editor (G. Knight) or the Technical Information Division, CANMET, Energy Mines and Resources Canada, Ottawa, Ontario K1A 0G1.

VoL. 6 Report 2

VOLUME 6 — GENERAL and UNCLASSIFIED
— DIVERS

73-17 M. Savich

Noise and Vibration in Canadian Mines

1973

Bruit et vibration dans les mines canadiennes

par

Miron Savich*

RÉSUMÉ

Dans les mines canadiennes, des efforts considérables ont été consacrés à la mécanisation, à l'augmentation de la vitesse de foration, à l'amélioration des méthodes d'exploitation, à la sécurité, etc., mais peu de mesures ont été prises pour réduire le bruit et les vibrations.

Cette situation se réflète dans le domaine scientifique par le nombre peu élevé de documents publiés à ce sujet. C'est surtout en Ontario et en Colombie-Britannique que des travaux sont réalisés dans le domaine de l'acoustique minière.

De nombreux organismes et sociétés minières possèdent des équipements pour mesurer le bruit mais pas les vibrations. La classification des critères de bruit se fonde sur la durée et le niveau d'intensité. On peut classer les expositions au bruit durant le travail en quatre groupes :

1. bruit continu à long terme
2. bruit continu à court terme
3. bruit intermittent d'intensité égale
4. bruit intermittent d'intensité variable.

Le niveau de bruit est déterminé par un sonomètre normalisé et fonctionnant sur un circuit de pondération A à réponse lente (expositions au bruit admissibles - valeurs limites seuils d'agents physiques adoptée par l'ACGIH en 1969). Les expositions au bruit inférieur à 90 dBA n'entrent pas dans ces calculs. Le bruit d'impact ne devrait pas dépasser le niveau C de pression sonore de pointe de 140 dB. La gamme de fréquences visée par les critères d'exposition aux vibrations proposés par l'ISO varie de 1 Hz à 1 000 Hz.

Au Canada, le bruit et les vibrations sont mesurés conformément aux normes internationales et aux normes nationales américaines.

L'effet du bruit sur le travailleur minier au Canada est surtout analysé sur le lieu du travail, dans la mine ou dans l'usine.

Bruit : vibration : perte en audition : normes

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Droits de la Couronne réservés.

L'analyse a montré que l'effet du bruit et des vibrations sur le communauté minière canadienne est très grande; par conséquent, dans les mines souterraines et les mines à ciel ouvert, cet effet est très élevé.

Dans les mines de charbon, l'analyse indique que l'objectif visé est d'augmenter le rendement et d'accroître la mécanisation, en particulier dans les mines à ciel ouvert. Compte tenu des données du Bureau of Mines, des gammes d'intensité sonore enregistrées dans des mines de charbon souterraines et du niveau sonore moyen mesuré dans les usines, nous pouvons conclure que la plupart des travailleurs subissent des intensités de bruit inadmissibles. La situation est encore plus grave si l'on applique la limite de 85 dBA.

Dans les mines métalliques souterraines, l'évaluation a pu être faite avec plus d'exactitude compte tenu du grand nombre de données recueillies. La détermination des expositions admissibles au bruit tient compte de données provenant de 82 mines et de 87 usines. Elles indiquent que 61 % des travailleurs sont exposés au bruit dans les mines et que 70 % le sont dans les usines. Dans les usines, l'évaluation serait plus exacte si l'on supposait que les travailleurs ne changent pas de position durant leur travail.

Les employés d'usine cités dans le rapport sont surtout ceux des mines de fer. L'évaluation réalisée avec soin a permis de constater que 29 % des travailleurs pourraient être surexposés. Cette évaluation correspond à la réalité.

Dans les mines à ciel ouvert, on peut s'attendre à un niveau de bruit élevé dû au fait que des engins lourds et puissants y sont utilisés. Aucune mesure, cependant, n'a été prise dans ces mines.

Dans les mines non métalliques, il n'y a pas de bruit, et dans les usines, les procédés technologiques ne sont pas bruyants. Ce n'est que dans les carrières de roche que les niveaux de bruit sont élevés.

La lutte contre le bruit industriel comprend :

1. la planification des installations;
2. le remplacement (l'utilisation d'équipements, de procédés et de matériaux moins bruyants);
3. la modification de la source de bruit; et
4. la modification de l'onde sonore.

Un petit manuel pourrait être rédigé pour aider les mines à résoudre ce problème et s'assurer que la lutte contre le bruit industriel est appliquée correctement.

Des efforts considérables ont été consacrés à l'atténuation des bruits suivants dans les mines :

1. Le bruit mécanique ou d'impact par des amortisseurs de bruit intégrés, des barrières isolantes, etc.
2. Les bruits aérodynamique et hydraulique de nouvelles machines, des amortisseurs de bruit, etc.
3. Le bruit magnétique par des barrières intégrées, etc.

Dans les mines, les solutions techniques au bruit sont rarement appliquées étant donné que le coût est l'un des principaux facteurs de production. Il en va de même des vibrations.

Pour cette raison, il est nécessaire de bien planifier la recherche future.

Le point le plus important et le plus fondamental est de recueillir le plus de données possibles afin d'identifier les sources de bruit qui doivent être atténuées. Il faudra entreprendre une étude des vibrations de la perforatrice sur le corps. Les conditions climatiques froides qui règnent dans les mines canadiennes contribuent probablement à l'augmentation des dommages corporels subis par les mineurs aux mains, aux bras et aux épaules.

L'analyse a montré que le bruit n'est pas un fait nouveau dans l'industrie minière canadienne. Dans l'avenir, les travaux planifiés et approfondis consisteront à :

1. instaurer une collaboration entre le gouvernement, les spécialistes du bruit, les sociétés minières et les fabricants d'équipement minier pour recueillir des données sur le bruit et les vibrations.

2. diffuser des informations sur les effets et les niveaux acceptables du bruit et les techniques de mesure du bruit et de lutte contre le bruit.

Les fabricants de matériel minier doivent :

1. évaluer le bruit produit par chaque machine conformément aux normes établies;

2. mettre au point des machines moins bruyantes.

Le présent rapport présente la situation qui existe en matière de bruit et de vibration dans des mines canadiennes. Ce rapport n'est pas et ne peut pas être définitif étant donné que les mesures qui seront prises pour réduire le bruit et les vibrations dans les mines au Canada sont appelées à évoluer. Il est probable que les producteurs et les concepteurs prendront de nouvelles mesures pour réduire le bruit et les vibrations. C'est pourquoi la situation évoluera et il est souhaitable, qu'à tous les deux ans, le rapport soit révisé et complété par de nouvelles données.

Noise and Vibration in Canadian Mines

by

Miron Savich *

ABSTRACT

In Canadian mines, great effort has been put into mechanization, drilling speed, mining methods, safety, etc., but little has been done to reduce the degree of noise and vibration.

This is reflected in the scientific field by the small number of publications. Mining acoustics activity is concentrated mainly in Ontario and British Columbia.

Many institutions and mines have equipment for measurement of noise but not of vibration. The classification of noise criteria is based on time duration and level of the noise. There are four classes in to which occupational noise exposures may be grouped:

1. long-term continuous noise,
2. short-term continuous noise,
3. intermittent equal intensity noise,
4. intermittent variable intensity noise.

The noise level is determined by a sound level meter, meeting the standards and operating on the A-weighting network in slow meter response (Permissible Noise Exposures - Threshold Limit Values of Physical Agents Adopted by ACGIH for 1969). Noise exposures of less than 90 dBA do not enter into calculations. Impact Noise should not exceed 140 dB peak sound pressure level - C. The vibration exposure criteria have been proposed in the I. S. O. for the range 1 Hz to 1000 Hz.

Canada uses the International standards and the American National Standards in the sound and vibration measurement.

The noise effect upon the man in the Canadian mines is mainly in the working place, in mine or mill.

The analysis showed that the noise and vibration effect upon the Canadian mining community is very small; therefore, in underground mines and open pits this effect is very great.

Noise: Vibration: Hearing Loss: Standards

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In coal mines the analysis showed a high performance and the involvement of great mechanization, especially in open pits. According to the data of the Bureau of Mines the sound level ranges for the occupations in underground coal mines, and the average sound level measured at mills, we can conclude that most of the workers are in the unpermissible noise levels area. The situation is worse if we apply the limit of 85 dBA.

In metallic underground mines the estimation was done more accurately because there were more data. The evaluation of the permissible noise exposures involved 82 mines and 87 mills. This showed that 61% are exposed to noise in mines and 70% are exposed to noise in mills. The evaluation in mills would be accurate if we suppose that the workers do not change their position during their work.

The Plant Force Report is related mostly to the iron mines. The evaluation was performed by a cautions analysis and it was discovered that 29% of workers could be overexposed. This evaluation corresponds to the reality.

In the open pit mines we can expect a high noise level because of the use of heavy and powerful machines. The measurements in this direction were not performed.

In the non-metallic mines there is no noise and in the mills the technological processes are quiet. Only in stone mines are the noise levels high.

Industrial noise control is composed of:

1. Plant Planning;
2. substitution (use of quieter equipment, process and material);
3. modification of the noise source; and
4. modification of the sound wave.

A short manual should be written which could help the mines overcome this problem and ensure that industrial noise control could be correctly applied in practice.

Great efforts have been made to reduce noise in mines:
1. Mechanical or impact noise, by built-in mufflers, barriers etc.
2. Aerodynamic and hydraulic noise with new inventions, mufflers etc.
3. Magnetic noise by built-in barriers, etc.

In mines the technical solutions are scarcely applied because cost is one of the main factors in production. The same thing applies in the case of vibration.

For this reason it is necessary to be well organized in the future research.

The most important and basic thing is to collect the most possible data to identify the specific noise sources for noise reduction purposes. We must start a study on the vibration on the rock drill and body. The cold weather conditions in Canadian mines contribute probably to the increase of physical damage to miners hands, arms and shoulders.

The analysis showed that the noise is not new to the Canadian mining industry. Future organized and extensive work will involve:

1. Organizing a cooperative effort among government, noise specialists, mines and mining machinery manufacturers to accumulate the noise and vibration data.

2. Disseminate public information on effects, acceptable levels, and techniques for measurement and control of noise.

The tasks of the mining machinery manufacturers are:

1. to evaluate the noise of each machine according to the standards;

2. to develop quieter machines.

This report represents the situation about noise and vibration in Canadian mines. The report has not and cannot have a definitive form because the resulting changes in the fight for noise and vibration reduction in mines in Canada will progress. Probably the producers and designers of the protection means will make new efforts for noise and vibration reduction. For this reason the situation will change and it is desirable that every second year the report should be revised and completed with new data.

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1. INTRODUCTION

1.1 History

The detrimental effect of noise has been known instinctively for thousands of years. Historians have established that the Pharaohs decreed a "law of silence". Thirty-five hundred years ago noise was considered a 'cause belli'. Wiethaup (1) reports that in the 3rd century B.C. the Chinese minister of police, Ming-Ti, made the following law: "who-ever insults the Highest is not to be hanged, but flutists, drummers and noisemakers should play to him uncessantly until he falls dead; for this is the most tormenting death for a "human being". At the foundation of the city of Sybaris the Romans ordered that no tradesman who used a hammer might exercise his profession with the city walls. Also in the old Roman law (as known through Pliny, about 100 A.D.) it was considered a duty of the state to care for peace and quiet of the population.

There were similar conditions in the Middle Ages. The faculties of law in the Universities of Leipzig and Jena decided in 1617 that no noisy tradesmen should settle near the residences of the "doctores", because they would force the scholars to give up their scientific work. It is also reported that city councils did not always show the required consideration.

In the Prussian General Country Law of 1793 one can find a note according to which "hooligan making noise on the street may be punished by prison or penitentiary". The philosopher Artur Schopenhauer has frequently dealt with the problems of generation and suppression of noise; he also published a detailed paper entitled "Noise and Sound".

The intensity of sound is a term which refers to the flow of energy in the sound waves. In several fields of work, including telephony and architectural acoustics, the common logaritham ($\log 10^n = n$) of this ratio, P_1/P_2 (the ratio of the flow of energy per second (power) of two sound, say P_1/P_2) is used. When this is done, the quantities obtained are said to be stated in bels (the decibel, one tenth of a bel). A unit called the bel, named after Alexander G. Bell (1847-1922), Canadian inventor and physicist (Figure 1).

In 1910, Dr. Robert Koch predicted, "One day man will have to wage war on noise just as unrelentingly as on disease and pestilence". Several pamphlets have appeared in Germany during the last 100 years, e.g. a paper by Young, "Bicycle Disease and Automobile Nonsense". Finally in 1926 Barkhausen brought on the market the first instrument designed to measure the noise in "phons".

In 1929 a committee was formed in the city of New York to study the noise of a great city. Swiss scientists have done considerable legal work during the last decades aimed at the suppression of noise. In Sweden, efforts for noise control on pneumatic mining equipment have been made systematically since the late 1940's. The Research Division of the Association of Swedish Mines formed a Noise Committee that has been occupied with the questions of how various levels influence the hearing of miners and of propaganda for ear protectors and silenced equipment (2).

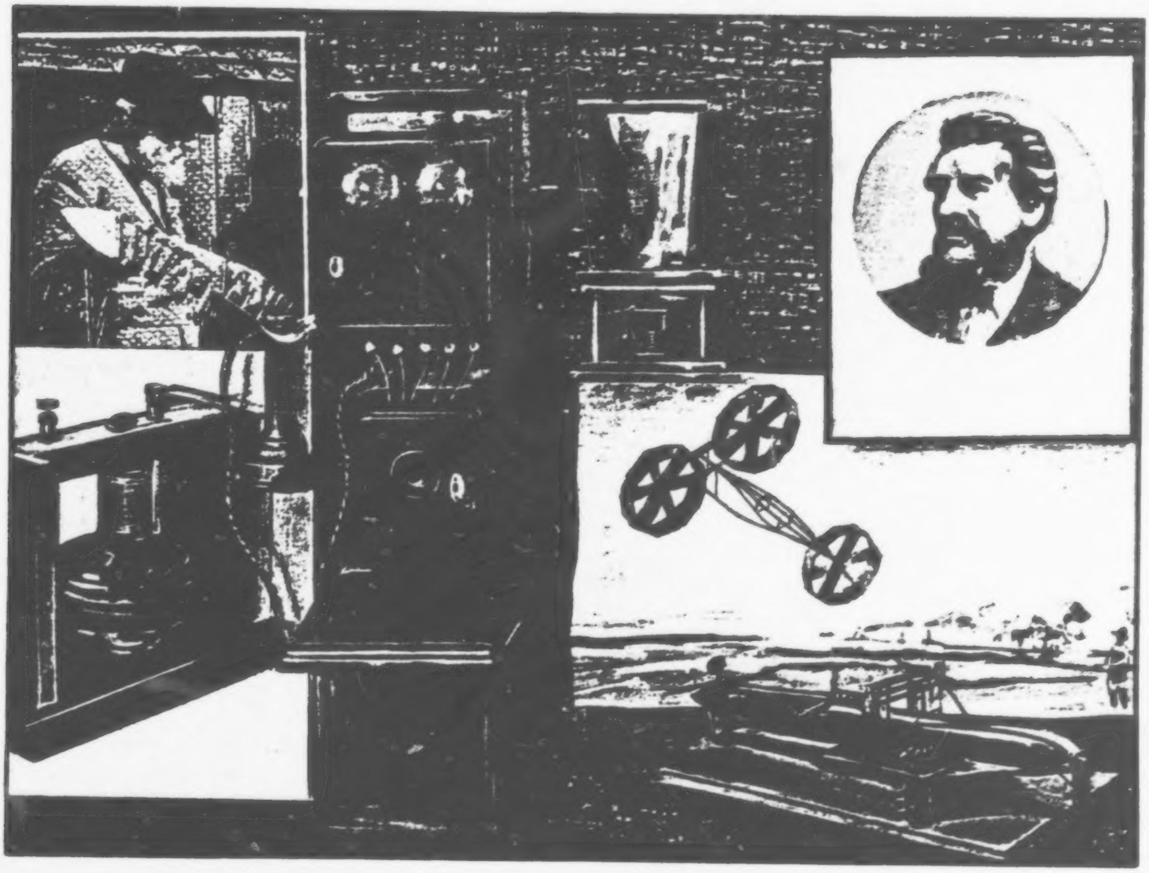


Figure 1: The Transmission of speech by telephone was first accomplished in 1866 by Alexander G. Bell.

The day predicted by Robert Koch has come. Noise has become a nuisance and a danger to everyone. But noise is not inescapable; it can be defined, measured, and effectively controlled.

1.2 Purpose and Scope

Since World War II, noise and its effect on man has been the topic of considerable research, but it was the Industrial Revolution after World War II which heralded the start of the noise age. The new factories, mines and steel mills brought pollution of all kinds - smells, fumes, eyesores and, of course, noise.

In mining, great effort has been put into mechanization, drilling speed, mining methods, safety, etc. but little has been done to reduce the degree of noise and vibration. The mufflers on small- or medium-weight drill hammers and the isolation of man from noise are just the beginning. In mining the quiet equipment costs more.

Miners must know enough not to be fooled into accepting unnecessary noise. Engineers must learn enough about noise to know when it can be kept down and to understand what the acousticians are talking about. Economy can no longer be the limiting design factor. This attitude must spread throughout the whole of industry and government.

The value of output of the Canadian mining industry was a record in 1970 for the tenth consecutive year. Several new mines started operating and production facilities at others were enlarged. Exploration activity continued in many parts of the country, extending as far north as the Canadian Arctic Islands. Development continued, particularly at iron, nickel, copper, uranium, zinc-lead and coal properties. The value of mineral production in 1970 (excluding petroleum and natural gas) was $4, 131 billion, 128 percent higher than the revised value of $3, 225 billion for 1967 (only crude minerals).

If the data from Table 1 is compared with that of Table 2, it can be seen that the increase in ore mined and rock quarried is very great but that the employment level from 1952 to 1966 stayed practically the same. This is explained by the opening of new, large, open pit mines and the increase of underground mechanization.

TABLE 1

Ore Mined and Rock Quarried.

Canadian Mining Industry, 1947-1966

(millions of short tons)

	Metal Mines	Industrial Mineral Operations	Total
1947	33.3	30.4	63.7
1948	36.9	33.5	70.4
1949	43.3	32.9	76.2
1950	45.9	41.8	87.7
1951	48.8	43.8	92.6
1952	52.3	44.2	96.5
1953	54.4	47.2	101.6
1954	59.0	61.5	120.5
1955	69.2	63.5	132.7
1956	77.4	73.0	150.4
1957	84.3	82.2	166.5
1958	78.8	78.5	157.3
1959	99.1	90.7	189.8
1960	101.6	97.8	199.4
1961	99.4	106.7	206.1
1962	114.2	114.5	228.7
1963	124.5	132.8	157.3
1964	141.2	147.8	289.0
1965	166.5	161.5	328.0
1966	162.8	178.5	341.3

Employment in the Mineral Industry for 1947, 1952, 1957, 1962, 1966, is shown in Table 2.

TABLE 2

Table of Employment in the Canadian Mining Industry

	1947	1952	1957	1962	1966
Metal mining	39,334	55,338	62,554	58,243	61,698
Non-Ferrous smelting and refining	17,449	24,608	29,613	29,093	33,237
Industrial minerals*	22,429	26,141	31,312	25,243	27,082
Fuels	25,307	28,029	21,985	21,129	21,796
	104,519	134,116	145,464	133,708	143,813

* includes cement, lime and clay and clay products manufacture.

The obvious result of this increased mechanization per employee is an increase in noise. The percentage of this increase is not known because comparative records have not been kept. According to statistical records, the measures taken to reduce noise and vibration have not kept pace with the increasing levels.

Industrial noise deafness became an industrial disease under the amendment of the Workmen's Compensation Act of Ontario in 1947 (3).

International Nickel Company of Canada began in 1954 by investigating the need for the introduction of a hearing programme to protect workers from industrial noise (4). Many mines have just started doing this, e. g. Cominco, Falconbridge.

On the list of publications registered between 1960 and 1970 (Table 3), Canada is in 16th place in the "Sound, Noise, Hearing Loss and Hearing Protection" group, and has no publications in the "vibration and shock" group. In the latter group, Bulgaria and Rumania, where mining exists practically for only 20 years, are ahead of Canada.

A few years ago, Canadian Ingersoll-Rand sold a greater number of light hammer drills to Rumania. The physical effects of vibration on the operator were overwhelming (the Raynard phenomenon).

Although the hammer drill had a feeding leg, the miner had to manage the hammer drill. Injuries increased (inflamation and swelling of the joints). The Rumanian standards determined the maximum permissible amplitude of vibration in hammer drills and forced Canadian Ingersoll-Rand to decrease piston travel distance and impacts per minute (5). This is an example of a government reacting quickly to imported tools and finding a solution for their faults.

"Many of the new developments in the recent past and present are coming from abroad. Pertinent examples are in areas of controlled blasting (Sweden), ground control in tunnelling (Europe), automated long-wall mining (England), percussion drilling (Sweden & Germany), rotary-percussion drilling (Germany), tungsten carbide (Europe), ventilation, heat, rock mechanics and shaft sinking (South Africa), and rock reinforcement (Australia)" (6).

These are some of the reasons for the need of a comprehensive research programme in this field. The third largest mining power in the world - Canada - has this obligation and it should make an energetic effort to formulate and promote a suitable policy towards this goal.

1.3 Approach

Sound is the result of two processes:

a) a physical change in the environment relating to pressure, and
b) a psycho-physical process which involves the transmission, perception, and interpretation of the sound in one's consciousness.

The two main qualities which we use to identify and describe sound waves are frequency (pitch) in H_z and intensity (loudness) in dB. The sound pressure is the force per unit area caused by the sound wave (vibration); the unit is 0.1 Newton/m^2 (N/m^2). The use of sound pressures in N/m^2 directly as a measure in sound measurements is not convenient, it is more convenient to use a relative scale of sound pressure in dB - scale ($2 \times 10^{-5} N/m^2$ = O dB - reference quantity).

Vibration is an oscillation wherein the quantity is a parameter that defines the motion of a mechanical system (7).

Threshold Limit Values refer to sound pressure levels that represent conditions underwhich it is believed that nearly all workers may be repeatedly exposed without adverse effect on their ability to hear and understand normal speech.

TABLE 3

Data of Noise and Vibration in Mines Publication Survey
1960 to 1970

Sound, Noise, Hearing Loss, Hearing Protection

Standing	Country	No. Publications
1.	BDR (W. Germany	174
2.	USA	138
3.	France	115
4.	UK	97
5.	Czechoslovakia	90
6.	USSR	86
7.	Switzerland	54
8.	DDR (E. Germany	43
9.	Italy	41
10.	Poland	37
11.	Australia	19
12.	Netherlands	16
13.	Sweden	15
14.	Austria	13
15.	Bulgaria	10
16.	Canada	8
17.	Finland	6
18.	Rumania	6
19.	Belgium	4
20.	Yugoslavia	3
21.	Denmark	2
22.	Luxemburg	2
23.	Brazil	1
24.	Hungary	1
25.	Portugal	1
26.	Spain	1

Vibration and Shock

Standing	Country	No. Publications
1.	USSR	62
2.	BDR (W. Germany)	26
3.	Czechoslovakia	26
4.	Italy	26
5.	Poland	21
6.	USA	18
7.	France	17
8.	Bulgaria	14
9.	UK	12
10.	DDR (E. Germany)	7
11.	Switzerland	7
12.	Rumania	6
13.	Japan	3
14.	Sweden	3
15.	Australia	2
16.	Austria	2
17.	Netherlands	2
18.	Yugoslavia	1
	Canada	0

The National Institute for Occupational Safety and Health recently recommended to OSHA that a limit of 85dBA be adapted for new installations while presently-enforced OSHA limits of 90dBA for a time-weighted 8-hour-day average would be retained. In the recommended noise standard are criteria for providing hearing examinations for employees, and suggested requirements for the types of audiometric instruments to be used.

The carrying out of the new recommendation will provoke both resistance of industry and high expenses. The original recommendation was adopted by all provinces without preliminary measurements and discussions. This is one more argument that, in the national interest, mining education, research and development must be expanded, and there is no time to lose (Figure 2).

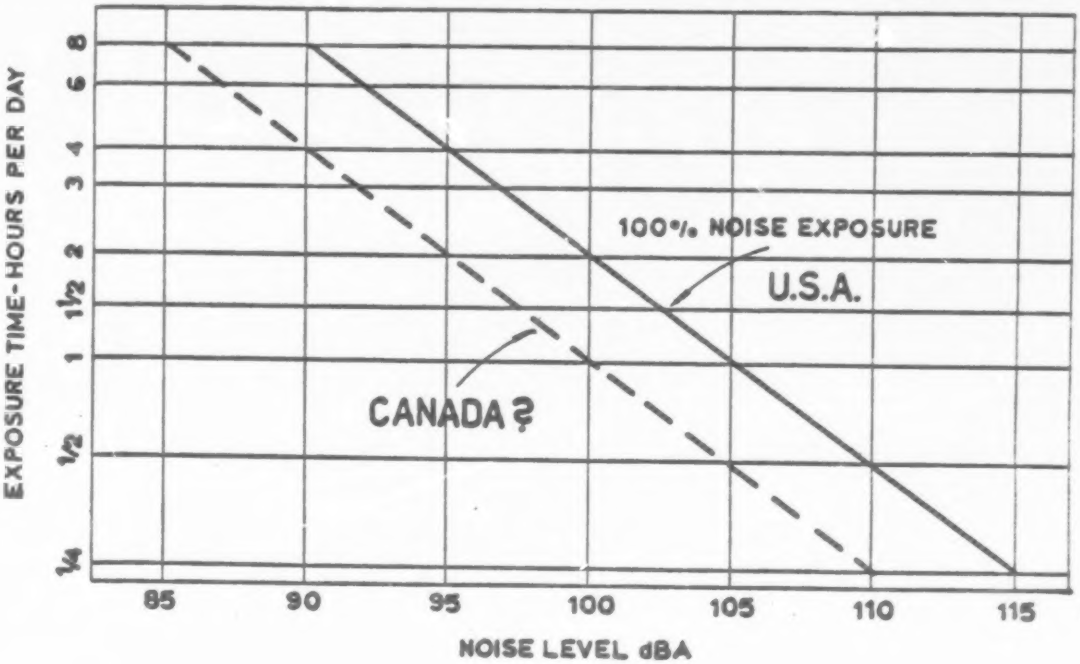


Figure 2: Permissible Noise Exposures.

Protection from vibration does not exist for miners; this is reflected in the number of publications. It is interesting that the Eastern Countries are paying too much attention to this problem.

Noise interferes with work, sleep, and recreation. It also causes strain, and fatigue, loss of appetite, indigestion, irritation, and headache. High-intensity noise has adverse cumulative effects on the human hearing mechanism, producing temporary or permanent deafness.

Psychologically, noise adversely affects the output of workers, decreases their efficiency, and increases their liability to error because of distraction from work.

Vibration problems occur in so many devices and operations that the number of types increase year by year; hence during the past decade more and more people have become concerned with the problems of vibration. Noise is even more important. In fact, it can be said that noise and vibration are twins. The study of sound is closely related to that of mechanical vibration, because sound is produced by the transfer of mechanical vibration to air.

The vibration disturbs the air particles near the object and sets them into motion, producing a vibration in normal atmospheric pressure. The disturbance spreads and when the pressure vibrations reach the human ear drums, they too are set vibrating. This vibration of eardrums is translated by a complicated hearing mechanism into the sensation called sound. Sound is produced by the transfer of mechanical vibration to air. Hence the process of "quieting" a machine or device often includes a study of the vibrations.

Acoustic noise is sound which, in the physical sense, is a mechanical vibration of particles either in a gas, a liquid or a solid. Such vibrations are characterized by their frequency, amplitude and phase.

Noise and vibration have become matters of some consequence in human affairs since the industrial revolution. The present generation has noise and vibration problems that previous generations did not have.

All mechanical vibrations cannot be perceived by the hearing mechanism of the human ear. Firstly, the vibrations have to be of a certain magnitude to be audible and secondly, the frequency has to be within certain limits. Not all vibration is necessarily harmful; some people find moderate levels of vibration exhilarating. Today it is possible to buy and the so-called "weight-control" machines which are built on simple vibration principles. However, the rock drill has a very high level noise and a very intensive vibration which may cause irrepairable physiological damages.

There is no quantitative proposal available from any quarter with respect to recommended or permissible vibrations for hand tool operation. We are just at the beginning of quantitative investigations.

To coordinate these global problems, the Mining Research Centre in Ottawa recommended that a new office be established within the Mining Research Laboratory in Elliot Lake. Great contributions can be made in helping to identify parameters, in measuring and interpreting data and helping to develop instrumentation.

1.4 Mining Acoustics Activity in Canada

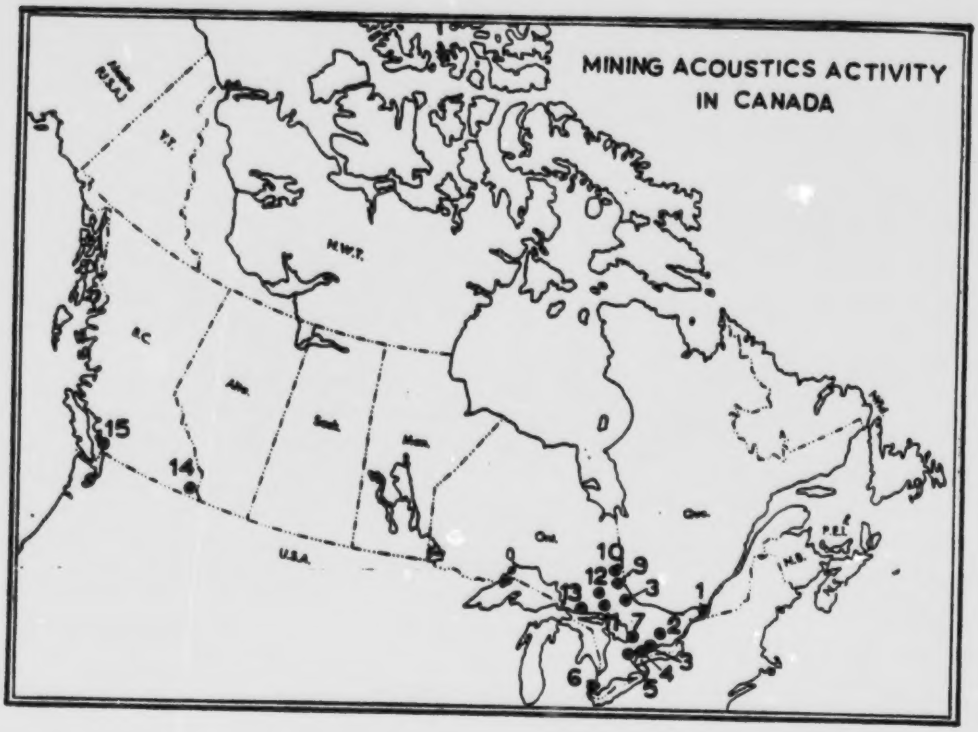
Canada is just beginning fundamental and practical research in mining acoustics. Industries (including mining) have their own services for tracking down and decreasing noise. At present, this takes place only in large companies.

Information on Canadian provincial or municipal legislation dealing with noise abatement in areas other than industry and motor vehicle noise control is very scanty. There are provincial regulations carried out by the Workmen's Compensation Boards and provincial statutes relating to highway traffic and municipal by-laws. The Federal Government passed the Motor-Vehicle Safety Act.

Province	Industrial Safety Act	Highway Code (Traffic Act)
Quebec	+*	+
Ontario	+*	+
Newfoundland	-	+
Prince Edward Island	+	+
Nova Scotia	+	+
New Brunswick	+	+
Manitoba	-	+
Saskatchewan	+*	+
Alberta	+	+
British Columbia	+*	+

* Mines Regulation Act

Up to now, Canada has accepted the U.S.A. standards, but is now starting to collaborate with international organizations and associations (e.g. WHO, ISO, ILO) and is participating on their committees.


MINING ACOUSTICS ACTIVITY IN CANADA
Y.T.
N.W.T.
B.C.
Alta.
Sask.
Man.
Ont.
Que.
P.E.I.
N.B.
U.S.A.
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15

1. Montreal
   - a) The Institute for Mineral Industry Research, McGill University, St. Hilaire.
   - b) Domtar Research Centre, Senneville, Ste. Anne.
   - c) Service de Santé, Montreal.
   - d) Ministère de la Santé, Hôtel du Gouvernement, Québec.
2. Marmoraton Mining Company, Marmora.
3. Toronto
   - a) Ontario Ministry of Health
   - b) University of Toronto
   - c) City Health Service
4. Cominco Ltd., Oakville
5. Joy Manufacturing Company, Galt
6. The University of Windsor
7. Indusmin Limited, Midland
8. MAPAO, North Bay
9. N. Morissette Diamond Drilling Limited, Haileybury
10. Upper Canada Mines Ltd., Dobie
11. Sudbury
    - a) The International Nickel Company of Canada, Limited
    - b) Falconbridge Mines Limited, Nickel Division
12. Moose Mountain Mine, Capreol
13. Elliot Lake Laboratory, Mines Branch, Elliot Lake
14. Cominco Ltd. (Sullivan), Kimberley
15. Department of Mines and Petroleum Resources, Vancouver

Figure 3: Mining Acoustics Activity in Canada.

At Canadian universities, practical and theoretical research and measurements are being done. Courses are usually given annually and include two-day courses at the IAPA training centre, Toronto, in June, August and October, and a 2 1/2-day course at the University of Toronto in June.

The following is a list of Canadian Centres for acoustical activity in connection with mines.

1. Montreal
   a) The Institute for Mineral Industry Research, McGill University, St. Hilaire
   -Montreal, Quebec
   -Anedioic Chamber
   -The CAGI-PNEUROP test
   b) Domtar Research Centre, Senneville, Ste. Anne de Bellevue (Quebec)
   -Aneohoic Chamber
   -Architectural Acoustics
   -Noise in Buildings
   c) Service de Santé, Montreal
   -Urban and Industrial Noise
   d) Ministère de la Santé, Hôtel du Gouvernement Quebec
   -The service for noise measurement.

2. Marmoraton Mining Company, Marmora.
   -Noise control in mines (made by Bethlehem)
   -Abatement of noise from different types of trucks.

3. Toronto
   a) Ontario Ministry of Health
   -Service for noise measurement and
   -Service for audiometric testing (8).
   b) University of Toronto
   -Industrial Accident Research;
   A Human Engineering Appraisal.
   c) City Health Service
   -Urban and Industrial Noise.

4. Cominco Ltd., Oakville
   -Noise control with sheet lead
   -Practical designs for noise barriers based on lead.

5. Joy Manufacturing Company, Galt.
   -Noise suppression of rock drills, construction of integral muffler by Jack E. Galmusky, Design Engineer.

6. The University of Windsor
The Industrial Research Institute of the University of Windsor.
-The new noise specifications now being legislated throughout North America.

7. Indusmin Limited, Midland
-Noise suppression at grinding mills.

8. MAPAO, North Bay
-Service for noise measurement at mines.
-Service for audiometric testing at mines.

9. N. Morissette Diamond Drilling Limited, Haileybury
-Muffler application and construction on diamond drills.

10. Upper Canada Mines Ltd., Dobie
-Muffled fans

11. Sudbury
a) The International Nickel Company of Canada Limited
-Pre-employment hearing test
-Periodic follow-up hearing tests are done at 6 to 12 month intervals (1969).
-Personal ear protective devices.
-Reduction of the noise at the source (silencers on fans).
-Enclosures for hoistmen.
-Noise control and comparative tests.
b) Falconbridge Mines Limited, Nickel Division
-Pre-employment hearing test.
-Periodic follow-up hearing tests are done at 6 to 12 month intervals (1971).
-Personal ear protective devices.
-Reduction noise sources in new refinery (1971) on steel ducting and blower blow-off stacks.
-Noise control.

12. Moose Mountain Mine, Capreol
-Enclosure (with the assistance of the MAPAO)

13. Elliot Lake Laboratory, Mines Branch, Elliot Lake
-Survey of noise in mines.

14. Cominco Ltd. (Sullivan), Kimberley
-Noise control (9)
-Construction of rubber muffler by J. W. Reynolds.

15. Department of Mines and Petroleum Resources, 320-890 West Pender Street, Vancouver 1,
    - Mining noise legislation
    - Sound survey

From the data mentionned above it can be seen that the mining acoustics activity is small in comparison with the number of mines in Canada.

2. PHYSICAL PROPERTIES OF NOISE, SOUND AND VIBRATION

Noise is disagreeable or unwanted sound. Vibrations (small, large, low frequency, or high frequency) all have their characteristic effect on the total noise produced. Noise, music and speech are three categories of sound. Speech is usually pleasant to the ear. Music may be agreeable. Noise is a complex subject.

2. 1 Sound

Acoustic noise is sound. Two primary attributes of sound are frequency and intensity. The frequency (low or high pitch), is measured in H_2.

$$\lambda = \frac{c}{f} \qquad \text{(Eq. 1)}$$

c = speed of sound, m/sec;
f = frequency, Hz
λ = wavelength, m.

The speed with which sound travels in air is dependent on temperature.

$$c = \sqrt{\frac{\gamma \cdot p}{\rho}} \qquad \text{(Eq. 2)}$$

p = the local atmospheric pressure, kp/cm^2;
γ = the ratio of the principal specific heat of the gas;
ρ = the local density, m/sec.

The velocity of sound propagation in various materials is different.

2. 2 Frequency

Frequency is the number of complete cycles of rise and fall in pressure in a given time.

The range of frequencies to which the human ear responds is from 20 Hz to about 20,000 Hz. Generally speaking, what the ear hears as pitch is the lowest audible frequency component in a complex wave.

Noise is complex in structure. For an understanding of the sound problem in industry, not only the magnitude of the sound must be measured, but also the frequencies. Sound is measured by means of a frequency analysis in octave bands or 1/3 octave bands.

2.3 Sound Intensity

In practice, it is found that an extremely large range of sound intensities are audible to man, and, in addition, perceived changes in intensity tend to be proportional to the ratios between the intensities concerned. It is thus more convenient to use a logarithmic unit to measure intensity - the decibel (dB). By definition, the intensity in decibels,

$$\mathrm{IdB} = 10 \log (I/I_0) \text{ dB} \qquad \text{(Eq. 3)}$$

where I is the intensity of a sound, W/m^2; and I_0 is a reference intensity, 10^{-12} W/m^2.

The reference intensity is chosen to be close to the threshold of hearing. Using the reference intensities, the intensity in decibels may be simply determined from the following equation:

$$\mathrm{IdB} = 10 \log I + 120 \qquad \text{(Eq. 4)}$$

where I is measured in W/m^2.

2.4 Sound Pressure Level

The sound pressure in a freely moving wave is proportional to the square root of the intensity; it is normally expressed in logarithmic units as the rms sound pressure level SPL, in decibels,

$$\mathrm{SPL} = 10 \log (P^2/P_0^2) \text{ dB re } P_0 \qquad \text{(Eq. 5)}$$

where p is the rms pressure of the sound, Newton/square meter (N/m^2)

P_0 is the reference pressure, 2×10^{-5} N/m^2 (this is equivalent to 2×10^{-4} dyn/cm^2 in the cgs system)

or

$$\begin{aligned}\mathrm{SPL} &= 20 \log (P/P_0)\\ &= 20 \log P + 94, \text{ dB re } 2 \times 10^{-5}\ N/m^2 \qquad \text{(Eq. 6)}\end{aligned}$$

where p is measured in N/m^2.

The reference pressure is chosen so that the numerical values for intensity and pressure in decibels are similar in many cases.

2.5 Sound Power Level

The sound pressure in a medium is naturally related to the power of the sound source; this power is measured in watts (W). However, since the range of power involved is very great, it is usual to employ a logarithmic scale for sound power; by definition the sound power level,

$$PWL_p = 10 \log (W/W_0) \qquad \text{(Eq. 7)}$$

where W is the sound power in Watts;
W_0 is the reference sound power, 10^{-12} Watts;

or PWL = 10 log W+ 120 dB (re 10^{-12} Watts) when W is measured in Watts. There are no instruments available for the direct measurement of sound power level but in certain circumstances this may be calculated from measurements of sound pressure levels.

2.6 Directivity Factor of a Radiating Noise Source

Most sources of sound of practical interest are directive. This may be of considerable interest in practice as most noise sources do not radiate the sound equally in all directions. If one measures the sound-pressure level in a given frequency band a fixed distance away from the source, different levels will generally be found for different directions.

Numerical measurements of the directionality of a source are the directivity index (DI) and directivity factor (Q):

$$DI_\theta = SPL_\theta - \overline{SPL_s} \text{ dB} \qquad \text{(Eq. 8)}$$

and

$$Q_\theta = \text{antiloq}_{10} \frac{DI_\theta}{10} \text{ dimensionless} \qquad \text{(Eq. 9)}$$

where: θ is all angles of the directional gain, and
$\overline{SPL_s}$ is the sound pressure level in spherical directivity pattern.

2.7 Combining Sound Levels

Sound pressure levels must be added or subtracted in the process of carrying out many different noise control procedures. The steps required to combine two such sound pressure levels are given in Table 4.

TABLE 4

Table for Combining Decibel Levels of Noises with Random Frequency Characteristics

Sum (L_R) of dB Levels L_1 and L_2

Numerical Difference between Levels L_1 and L_2	L_3: Amount to be added to the higher of L_1 or L_2
0.0 to 0.1	3.0
0.2 to 0.3	2.9
0.4 to 0.5	2.8
0.6 to 0.7	2.7
0.8 to 0.9	2.6
1.0 to 1.2	2.5
1.3 to 1.4	2.4
1.5 to 1.6	2.3
1.7 to 1.9	2.2
2.0 to 2.1	2.1
2.2 to 2.4	2.0
2.5 to 2.7	1.9
2.8 to 3.0	1.8
3.1 to 3.3	1.7
3.4 to 3.6	1.6
3.7 to 4.0	1.5
4.1 to 4.3	1.4
4.4 to 4.7	1.3
4.8 to 5.1	1.2
5.2 to 5.6	1.1
5.7 to 6.1	1.0
6.2 to 6.6	0.9
6.7 to 7.2	0.8
7.3 to 7.9	0.7
8.0 to 8.6	0.6
8.7 to 9.6	0.5
9.7 to 10.7	0.4
10.8 to 12.2	0.3
12.3 to 14.5	0.2
14.6 to 19.3	0.1
19.4 to ∞	0.0

Step 1: Determine the difference between the two levels to be added (L_1 and L_2).

Step 2: Find the number (L_3) corresponding to this difference in the Table.

Step 3: Add the number (L_3) to the highest of L_1 and L_2 to obtain the resultant level ($L_R = L_1 + L_2$).

2.8 Noise Analysis

Sound level meters are normally equipped with three frequency weighting networks (A, B and C). The A-frequency weighting is intended to approximate the ear's response below 55 dB re. 0.0000 N/m^2; the B-frequency weighting is intended for levels between 55 and 85 dB; and the C-frequency weighting corresponds to levels above 85 dB. The A-frequency weighting (dBA), found in many noise regulations, may also be calculated from noise spectrum valves (United States of America Standards S1.4 - 1961).

The octave band is commonly used in industrial noise measurements, in noise control work and in the effects of noise on the ear.

When a noise spectrum has a considerable amount of its energy concentrated within a narrow frequency band, it may be necessary to have more specific information than is provided by octave bands. One-third octaves may be used for this purpose.

Details of noise measurement and analysis techniques may be found in the references.

2.9 Theory of Vibration

When an object with a mass moves back and forth in a direction, it is said to vibrate. Vibration will be reviewed in three classifications: Periodic, Transient and Random.

Periodic vibration is the form most generally measured on rotating or reciprocating machinery and represents a periodic motion. Also known as Simple Harmonic Motion (SHM), this type of vibration repeats itself in all its particulars after a certain interval of time called the period, T. Simple Harmonic Motion is represented in mechanics by an equation in which the acceleration is proportional to the displacement. The plot of displacement against time (Figure 4) of SHM is a sinusoidal wave for which the function is:

$$X - A \sin \omega t \qquad \text{(Eq. 10)}$$

where X represents the displacement, A represents the amplitude, ω is the circular frequency or the angular velocity, and t is the time.

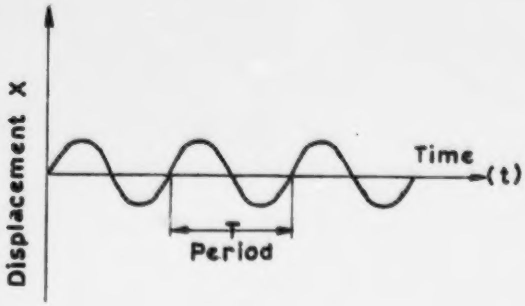


Figure 4: Sinusoidal Wave of SHM. The frequency (Number of cycles per unit time) is given by $F = {}^{1}/_{T} - \frac{\omega}{2\pi}$.

The relationships between the three quantities defining the SHM, are given in Table 5.

TABLE 5

Relationships between Quantities of SHM

Given Quantity	Transferred to		
	s	v	a
s $s = s_0 \sin(\omega t)$		$v = \frac{ds}{dt}$ $v = \omega s_0 \cos(\omega t)$	$a = \frac{d^2 s}{dt^2}$ $a = -\omega^2 s_0 \sin(\omega t)$
v $v = v_0 \sin(\omega t)$	$s = \int v dt$ $s = - {}^{1}/_{\omega} v \cos(t)$		$a = \frac{dv}{dt}$ $a = \omega v_0 \cos(\omega t)$
a $a = A_0 \sin(\omega t)$	$s = \iint a dt^2$ $s = \frac{1}{\omega^2} A_0 \sin(\omega t)$	$v = \int a dt$ $v = \frac{1}{\omega} A_0 \cos(\omega t)$	

Graphically, these quantities can be represented as in Figure 5.

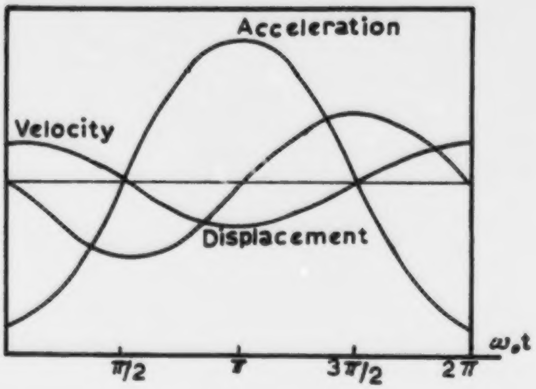


Figure 5: Relationships between Quantities of SHM (From Kimsler and Frey) (1).

To further explain Table 5 and Figure 5, it is seen that the velocity leads the displacement by a time interval corresponding to $\pi/2$ radians of phase-angle difference. Acceleration and displacement are always π radians out of phase with each other. The curves plotted in Figure 5 correspond to phase angle difference $\phi = 0$ and circular frequency $\omega_0 = 2$.

Taking the first derivative of equation 10, the velocity term is obtained:

$$V = \dot{X} = \omega A \cos\omega t = \omega A \sin(\omega t + \pi/2) \qquad \text{(Eq. 11)}$$

which indicates the $\pi/2$ difference in phase with the displacement term:

$$a = \ddot{x} = -\omega^2 A \sin\omega t \qquad \text{(Eq. 12)}$$

Since $x = A \sin\omega t$, then

$$a = \ddot{x} = -\omega^2 x\ ; \qquad \text{(Eq. 13)}$$

hence the definition of SHM is proved. In passing, it can be mentioned that in most vibratory equipment, accelerations are designated as multiples of the gravitational acceleration, g.

Transient vibrations are due to forces applied to a mass for a short interval of time and then removed. The subsequent motion of the mass is free vibration which gradually decreases in amplitude due to damping present in the system. Mechanical shocks and percussive sounds can be represented by functions which create the transient vibrations.

The vibrations which are unpredictable and are not limited by defined time intervals are called random vibrations; aircraft, traffic noise, air-cushion vehicles and mass conversations are examples of random vibration.

Thus far, some basic definitions of vibration theory have been reviewed. Since disturbances are irregular, some methods have evolved in order to compare the quantities defining a particular vibration, mainly, a) peak-to-peak values and b) root mean square (r. m. s.). The root mean square of, say, acceleration, is defined as the root of the mean square of the instantaneous values. In case of sinusoidal vibration, rms is equal to 0. 707 of the peak acceleration. For complex waves of random vibration, rms of acceleration is given by

$$a_{rms} = \sqrt{\frac{1}{T} \int_0^T \left| a^2 \quad t \right| dt} \qquad \text{(Eq. 14)}$$

Another important quantity is the average value of the acceleration

$$a_{average} = \frac{1}{T} \int_0^T \left| a \right| dt \qquad \text{(Eq. 15)}$$

For sinusoidal waves, these quantities are given in Figure 6, where $a_{peak} = \frac{\pi}{2} a_{average}$.

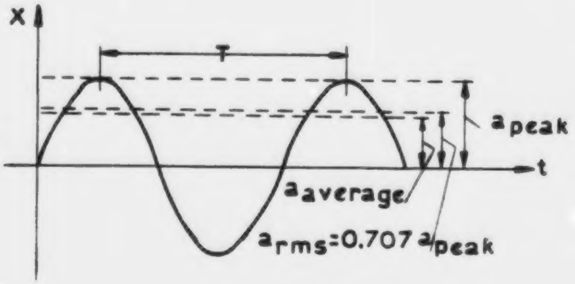


Figure 6 : Relevant Terms for Sinusoidal Wave.

The tendancy in studying vibration is to refer to sinusoidal waves most of the time because they are simple to deal with. However, in practice, wave shapes are more complex. Fortunately, all these complex waves can be handled by using the Fourier Series which makes it possible to represent any shape by a combination of a number of sinusoidal waves.

3. NOISE CRITERIA

Criteria may be established for several purposes: operator hearing protection, community hearing protection, community noise annoyance and speech interference, to name a few. In this report the prime purpose is to establish the types of noise environments to which an operator of mines or heavy equipment might conceivably be exposed.

For this report, the classification will be based on the time duration and level of the noise. Using time and level as the measure, there are four classes into which occupational noise exposures may be grouped:

1. Long-term continuous noise,
2. short-term continuous noise,
3. intermittent equal-intensity noise, and
4. intermittent variable-intensity noise.

3.1 Long-Term Countinuous Noise

Long-term continuous noise is defined as noise of an approximately constant level and spectrum, to which a listener is exposed for 6 to 8 hours per day, 40 hours per week, 50 weeks per year. Into this class of noise environment fit the majority of miners and a large portion of the heavy equipment operators working within the mine and mill system. Most criteria are written for this type of operator-exposure because it is the easiest to define in amplitude, frequency content, time duration, and resulting hearing loss case histories.

Figure 7 shows the three most common damage risk (DR) curves for continuous noise in use today (10). The upper curve (serious risk) infers permanent damage to anyone subjected to the noise field. The Normal Risk Curve is designed statistically to protect about two-thirds of the listeners. The lower curve (Negligible Risk) infers that the noise environment is safe for everyone.

These curves form the basis for other criteria established to evaluate continuous long-term noise (Figures 8, 9, 10 and 11). The MIL -S1 - 10 criterion (U.S. Navy) in Figure 8 is based on a short duration, typical to-the-noise environment in shipboard duty. The remaining curves in Figure 9 through 12 have an explanation of the criteria attached to define the test procedures or the basic applicability.

The American Conference of Governmental Industrial Hygienists proposed a criterion which states that for a 4-to-8 hour per day exposure over a working life, the noise level should not exceed 92 dBA.

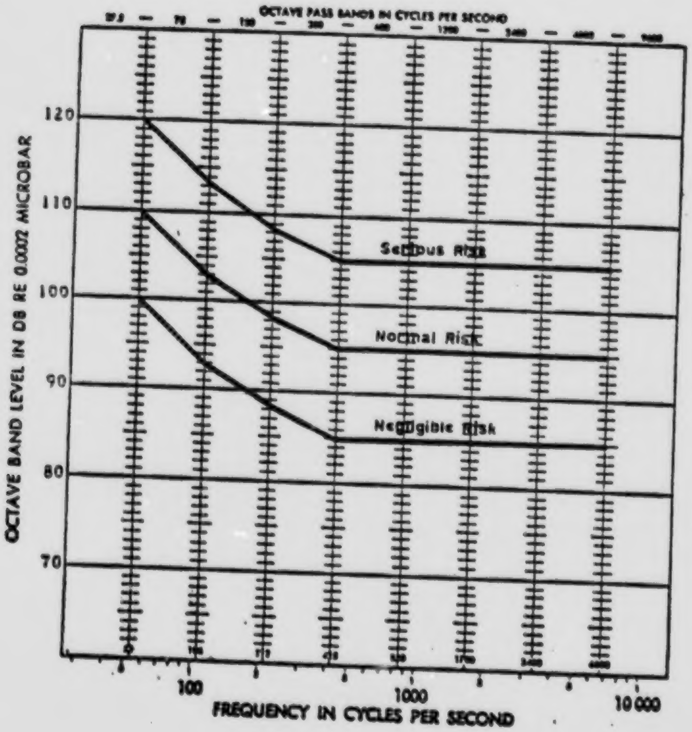


Figure 7: Typical Wide Band
Damage Risk Criteria (10), after Bolt, Beranek and Newman.

Another criteria is contained in the regulation under the Walsh-Healey Public Contracts Act (11). The permissible noise level for an 8-hour day is 90dBA and any noise level over 90 dBA will warrant administrative and engineering controls (12).

The application of this Act was accomplished in U. S. A. coal mines on small sample size; it was established that the Walsh-Healey criteria are more stringent than the Committee on Hearing, Biomechanics and Bioacoustics (CHABA) criteria. No measurements were made in Canada.

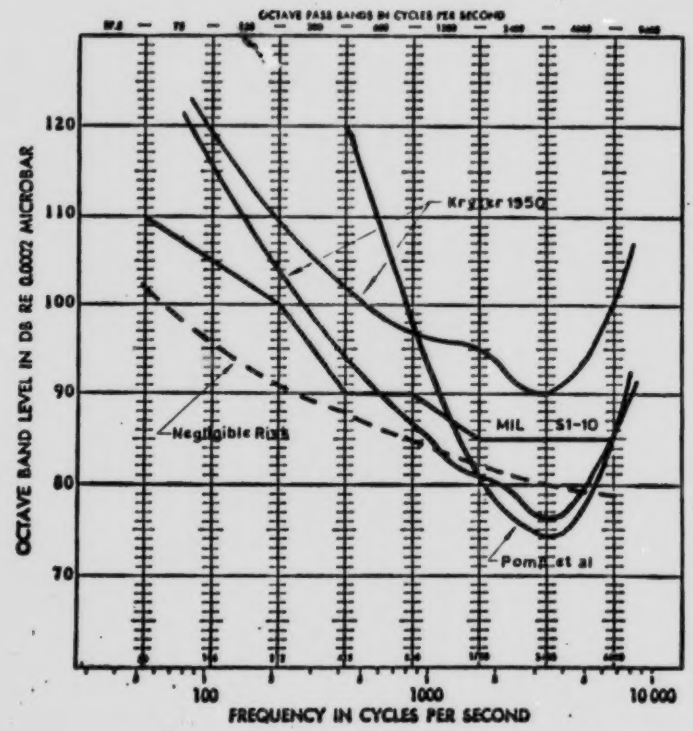


Figure 8: Damage Risk Criteria.

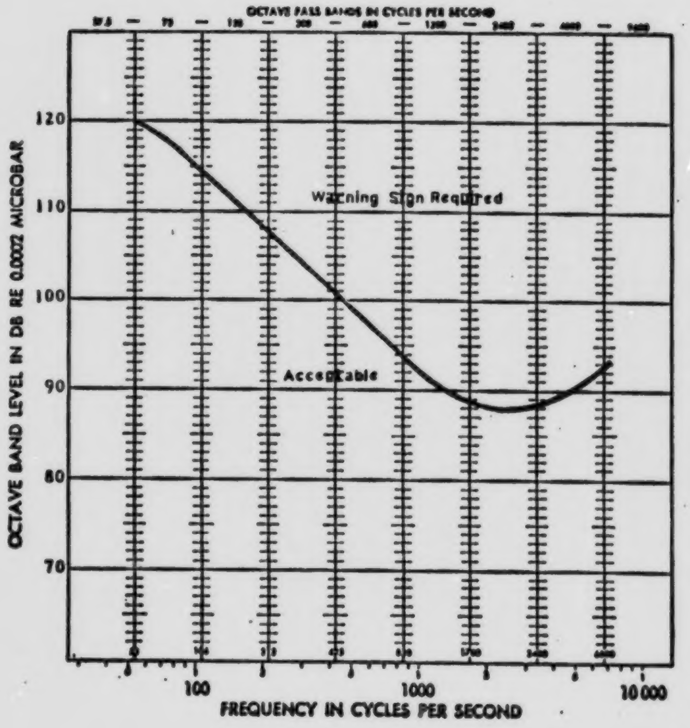


Figure 9: U.S. Army Human Engineering Laboratory Standard S-1-63 (13).

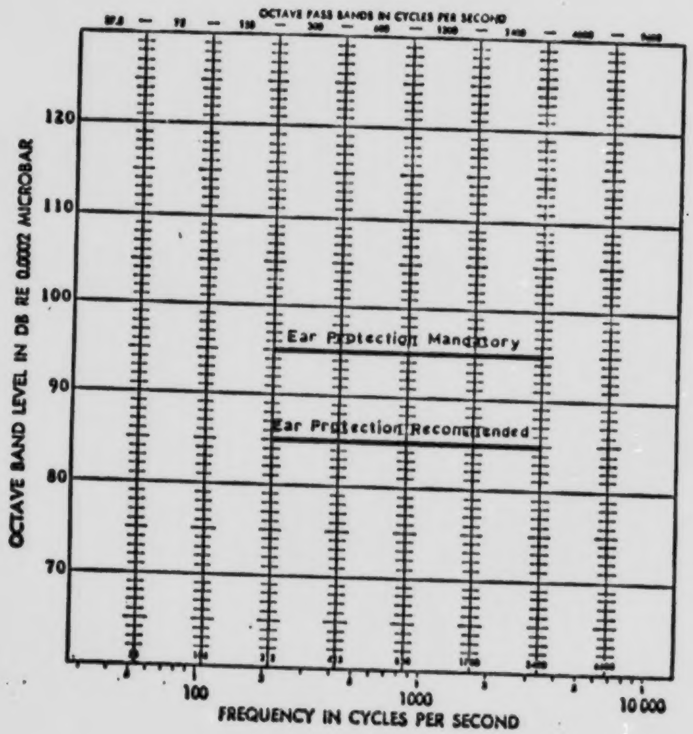


Figure 10: U.S. Air Force Regulation 160 - 3A (1960) (13).

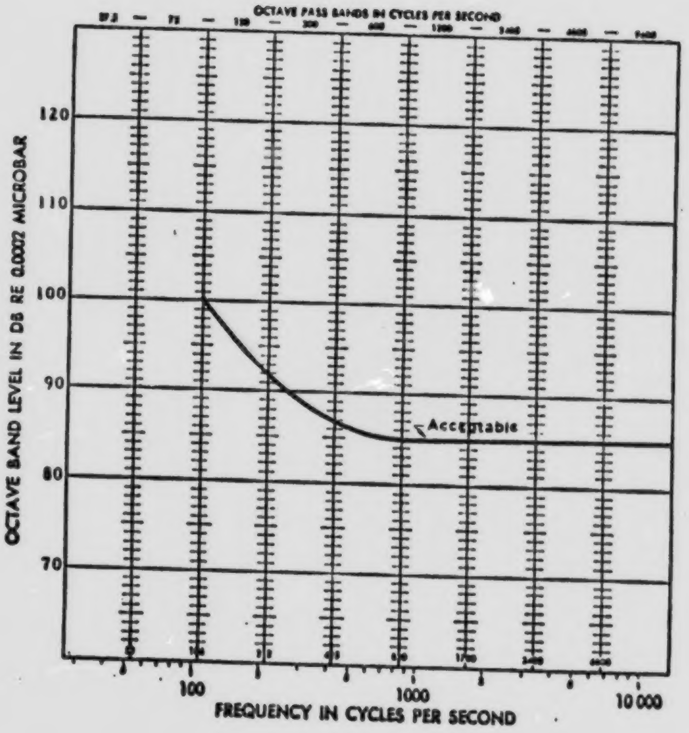


Figure 11: Standard of Massachusetts Institute of Technology (1950) after Leo L. Beranek.

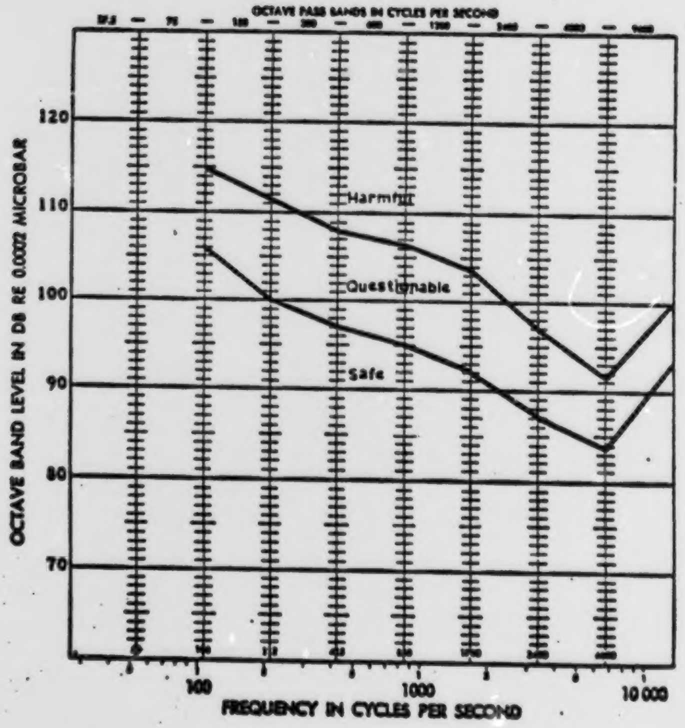


Figure 12: An early Criteria Set by a Research Foundation (1952) (13).

3.2 Short-Term Continuous Noise

Short-term continuous noise exposure may be defined as broad-band noise at an approximately constant level for less than 5 hours per day, 5 days per week for life. Only the octave bands of 300 - 600, 600 - 1200 and 1200 - 2400 Hz are considered, since these bands are of major importance in the protection of hearing for speech (Figure 13). There are three general criteria for noise exposure of this type.

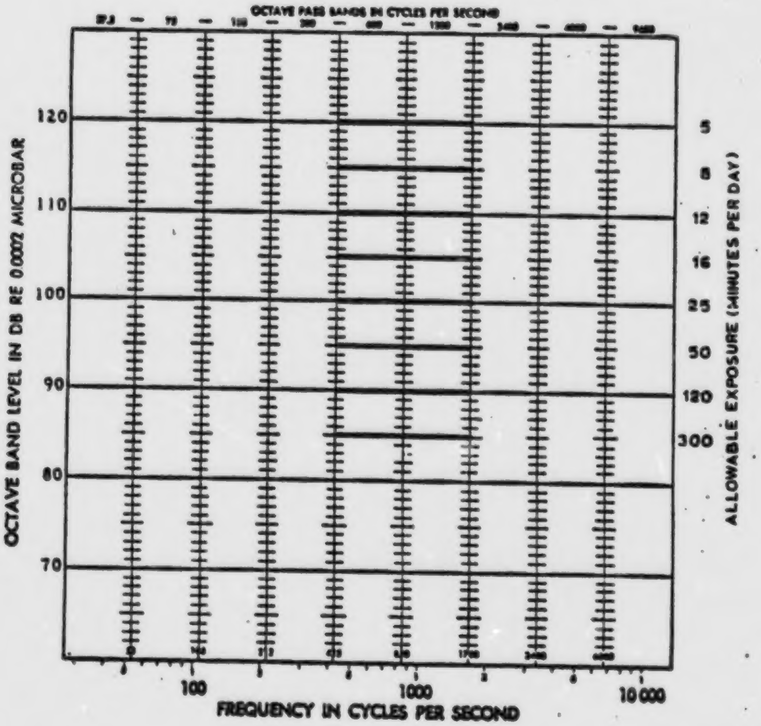


Figure 13: Noise Standard of the American Academy of Ophthalmology and Otolaryngology.

1. Exposure to broad-band noise is habitual, the noise is continuous, and the average in the three octave bands exceeds 85 dB. The most common criteria for noise exposure is the equal energy criterion which allows for a 3 dB increase in the permissible sound pressure level for every halving of exposure time. Using the criteria mentioned in the preceding section on continuous long-term noise, 3 dB might be added for every halving of time.

Standards by the department of Labor (14) for short-term continuous noise are presented in Table 6.

TABLE 6

Safety and Health Standards for Short-Term Continuous Noise

Hours per day	Sound Level dBA
8	90
6	92
4	95
3	97
2	100
1.5	102
1	105
0.5	110
0.25 or less	115

This Standard is also used in the analysis of intermittent variable noise.

2. Exposure to broad-band noise is habitual for less than 5 hours per day, and the average in the three octave bands exceeds those valves in Table 7.

TABLE 7

Criteria for Habitual Exposure to Continuous Noise for Less than 5 Hours Per Day (15).

Average level of 300 - 600 600 - 1200 1200 - 2400 Hz bands	On-time per day (minutes)
85 dB	Less than 300
90 dB	Less than 120
95 dB	Less than 50
100 dB	Less than 25
105 dB	Less than 16
110 dB	Less than 12
115 dB	Less than 8
120 dB	Less than 5

The Noise Standard of the American Academy of Ophthalmology and Otolaryngology based on daily exposure of broad band steady noise (Figure 13), has lined levels which represent the average of the 3 octave bands. This method has ready application in the realm of intermittent noise and will be discussed later. The Equivalent Continuous Sound Pressure Level method is directly applicable to short term continuous noise exposure and presents the safe allowable sound pressure levels for varying exposure durations. This criterion is concerned only with the octave bands, which cover the intelligible speech range.

3. For habitual short-term exposure to continuous steady noise that is on less than 5 hours per day, the need for hearing conservation measures may also be determined using Figure 14. This diagram shows the sum of the Temporary Threshold Shift (TTS) at 2000 Hz due to exposure to 600 - 1200 Hz noise as a function of level (16). Noise rating numbers (N) may be determined if the exposure time is known.

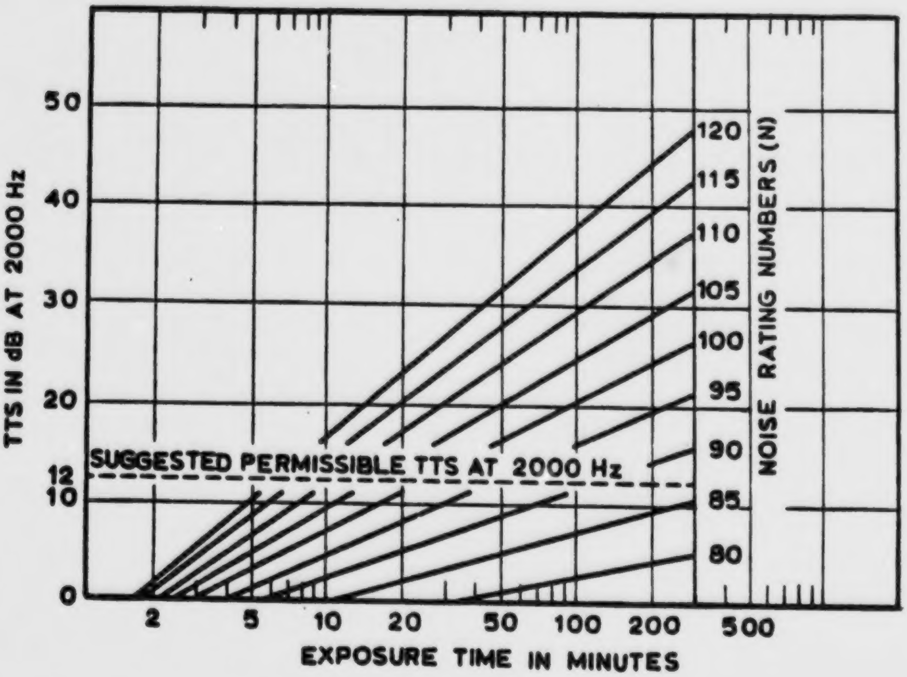


Figure 14: Noise Rating Numbers for Rating Short Term Exposure (16).

For example, if it is known that an exposure will be of 50 minutes' duration, the N is 95 because 50 minutes and N 95 inspect at 12 dB TTS. It is suggested that 12 dB TTS at 2000 Hz be used as a criterion to determine the noise rating, but regardless of the amount of TTS chosen, Figure 14 can still be used for rating short-term noise exposures. The permissible exposure time as a function of N may be ascertained by determining where the N line intercepts 12 dB TTS.

3.3 Intermittent Equal-Intensity Noise

Intermittent equal noise exposure may be defined as exposure to a given broad-band sound pressure level several times per day during a normal working day (Mill Superintendent, Mill Engineer, etc.). Figures 14 through 18 contain some of the common criteria for intermittent noise control.

One of the more common criteria applicable to intermittent noise exposure is K. D. Kryter's "Recommended Allowable Exposure Time for Intermittent Noise" (Figure 18) (17, 18). When the exposure to broad-band noise is intermittently on during the work-day, the recommended allowable exposure time may be determined by consulting this figure. It shows the relationship between the duration of the "on-time" between the noise bursts (ordinate), and the allowable average level of the 300 - 600, 600 - 1200, and 1200 - 2400 Hz bands. The broken contours show the number of permitted exposure cycles ("on-time" - "off-time" combinations) per day, calculated for a working day of 480 minutes. For example, if the average of the level at the 300 - 600, 600 - 1200, 1200 - 2400 Hz band is 105 dB and the noise is habitually on ("on-time") for 10 minutes, the "off-time" between noise bursts is the ordinate value of the intersection of 10 minutes and the 105 dB contour. In this case it is just under 40 minutes, or approximately 10 exposure-cycles per day.

Several subsequent proposals, the Intersociety Guidelines and Threshold Limit Values (TLV) for Noise of ACGIH, are more or less based upon this proposal.

3.4 Intermittent Variable Noise Criteria

Intermittent variable noise represents the most general noise environment to which an individual may be exposed and forms a close description of most mining and metallurgical exposure patterns.

Intermittent variable noise may be defined as broad-band noise which is intermittent in time duration and variable in both duration of "on" and "off" time and absolute magnitude.

Two basic methods for predicting damage by this type of exposure are currently available.

1. The Equivalent Continuous Sound Pressure Level Method, and
2. Temporary Threshold Shift Method.

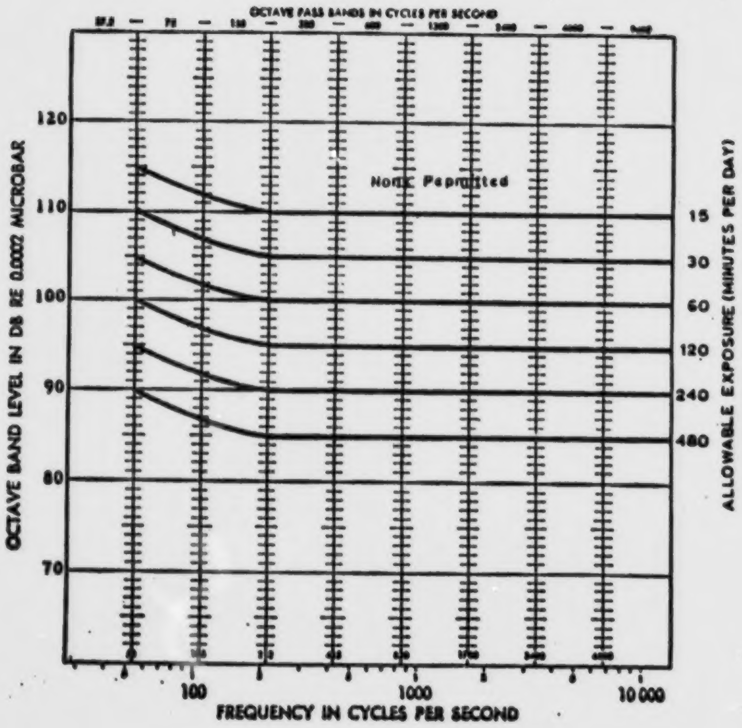


Figure 15: One Industrial Safety Guideline (1962) (15).

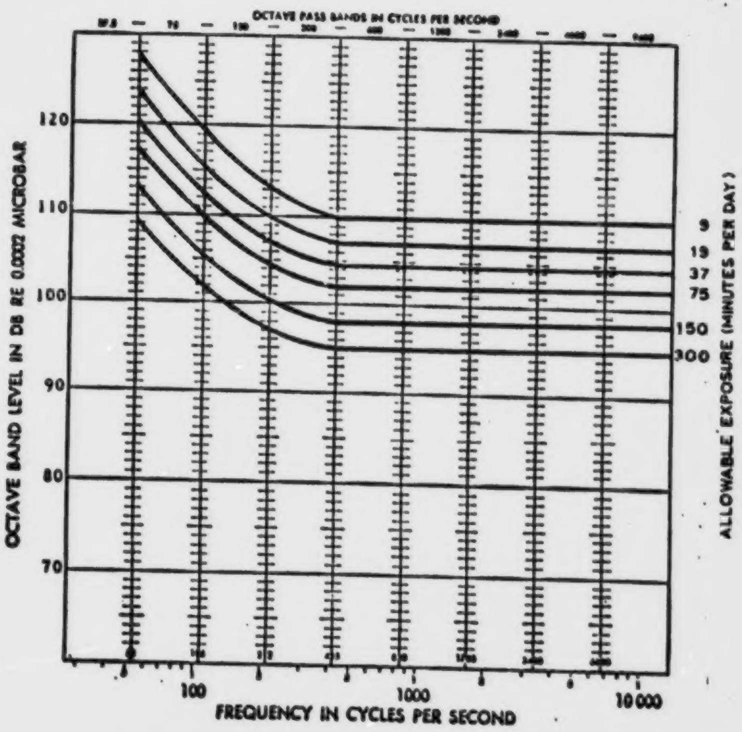


Figure 16: State of California Noise Control Safety Order Article 55 (1963) (15).

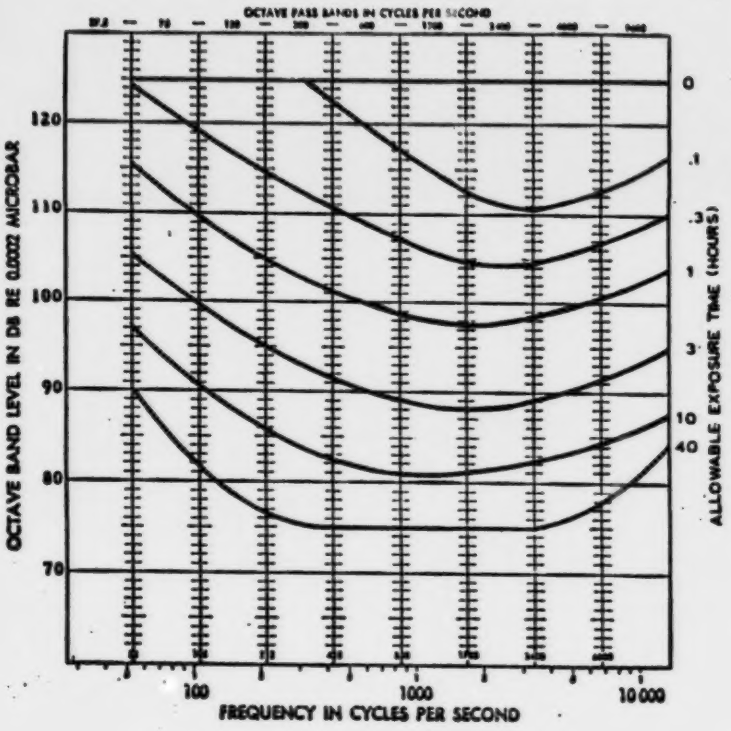


Figure 17: One in Plant Criteria for Intermittent Steady Noise (15).

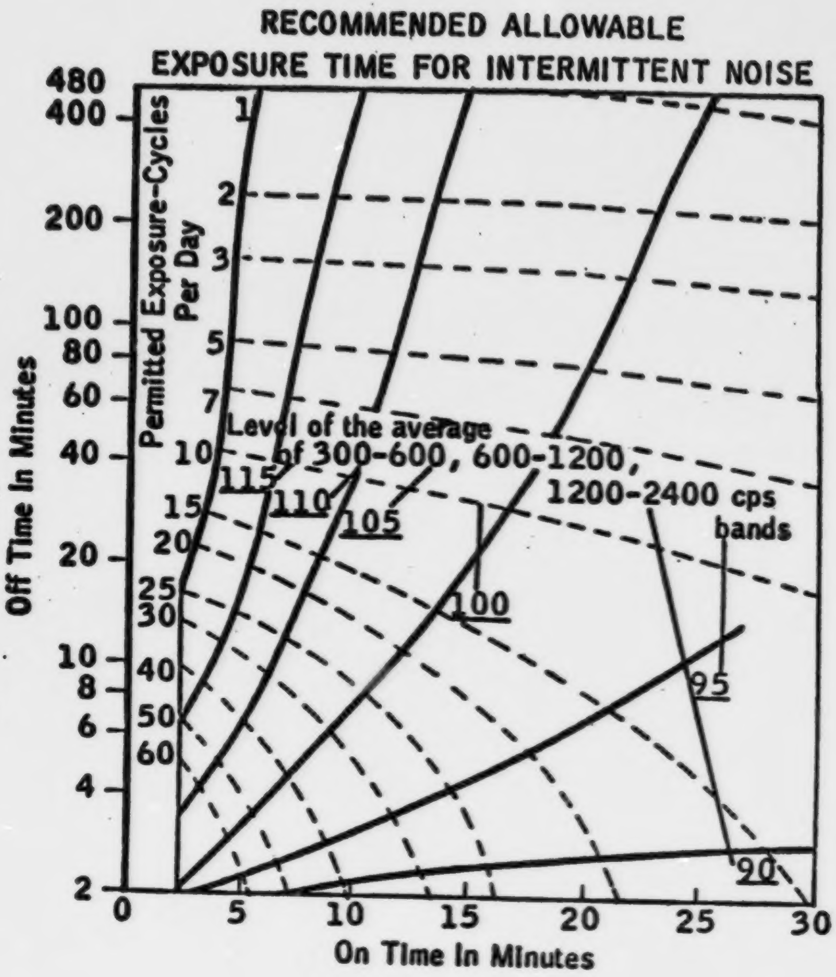


Figure 18: Noise Rating Numbers for Intermittent Noise Exposure, after K. D. Kryter.

No single method has yet been proven completely. The existing methods will be presented to illustrate the techniques involved in their application.

3.4.1. The Equivalent Continuous Sound Pressure Level Method

The Equivalent Continuous Sound Pressure Level Method was presented and supported by the International organization for standardization I. S. O. (19) and was also proposed for the American National Standards Institute, ANSI. This approach attempts to integrate one week's exposure to intermittent variable noise and obtain an equivalent noise level such that a continuous 40-hour exposure to this derived level would present the same potential hazard to hearing as the intermittent variable exposure. ISO Recommendation, R 1999, May 1971, is used in this method. This Recommendation may also be used in conjunction with other criteria mentioned earlier and may further act as an indicator for dBA measurements directly, to provide percent risk for various populations or classes of equipment operators.

3.4.2. Temporary Threshold Shift Method

Temporary Threshold Shift Method (TTS) computes and accumulates exposure to noise of any type (17, 20, 21, 22, 23, 24). The most important is the fact that this method attempts to predict mathematically the ear's reaction to a given noise dosage. This method presents a mathematical model for the threshold shift / recovery mechanisms of the ear. In addition, for TTS presented above, a recent study in England at the National Physical Laboratory by D. W. Robinson (22, 23) has derived an equation to predict the permanent noise-induced component of hearing loss PTS for exposure periods from 1 month to 50 years.

Robinson's work has pointed out the functional relations necessary in the analysis of damage risk criteria. It is hoped that future work based on this work will provide a powerful tool in the analysis of intermittent variable noise. A new method for computing the exposure from a noise environment has been adapted by the Intersociety Committee on Guidelines for Noise Exposure Control (Table 8).

The sound level shall be determined by a sound level meter, meeting the standards of the United States of America Standards Institute and operating on the A-weighting network with slow meter response.

TABLE 8

Permissible Noise Exposures*

Duration Per Day Hours	Sound Level dBA[a]
8	90
6	92
4	95
3	97
2	100
1-1/2	102
1	105
3/4	107
1/2	110
1/4	115-C[b]

a) Sound Level in Decibels as Measured on a Standard Level Meter Operating on the A-weighting Network with Slow Meter Response.

b) Ceiling Value.

* Threshold Limit Values of Physical Agents Adopted by ACGIH for 1969.

When the daily noise exposure is composed of two or more periods of noise exposure of different levels, their combined effect should be considered, rather than the individual effect of each. If the sum of the following fractions exceeds unity, i. e.,

$$\frac{C1}{T1} + \frac{C2}{T2} + \ldots \frac{Cn}{Tn} > 1$$

where C1 indicates the total time of exposure at a specified noise level;
T1 indicates the total time of exposure permitted at that level;

then the mixed exposure should be considered to exceed the threshold limit value. Noise exposures of less than 90 dBA do not enter into the above calculations. Impulsive or Impact Noise should not exceed 140 dB peak sound pressure level-C.

This method has one major drawback in that a noise environment is either completely safe or unsafe.

4. EFFECTS OF VIBRATION

Controlled vibration can be used effectively to aid mankind in such instances as conveyor systems and hopper discharge points. However, vibration usually has an adverse effect, such as human discomfort and fatigue from excessive vibration of a tool, fatigue and rupture of structural members and increased breakdown of machines, appliances and other devices.

Vibration then, is of concern not only due to noise, annoyance and discomfort but also due to safety aspects. The present refinements of high speed planes, ships, automobiles and pneumatic tools could never have been achieved without thorough measurement and study of mechanical vibration.

Vibration - related problems can be classified as:

1. Effects on man:
Many people who use pneumatic tools suffer from vascular disturbances which produce a local anemia or pallor of the fingers, making them stiff and awkward. It is rather surprising that very little attention has been paid to a reduction of the high levels of vibrations in all pneumatic machines.

2. Mechanical failure:
Excessive vibration leads to excessive stress, as well as fatigue, destructive impacts, and other effects that cause excessive wear resulting in high costs for machinery maintenance. Periodic measurement of machinery vibration has become an important preventative maintenance procedure in many factories. Limits on vibration on many machines have been set for a variety of reasons, generally on the basis of experience. Thus, knowledge of vibration should help to insure high quality of work and low maintenance.

Rathbone (25) recommended in 1963 that, for hand tools, the velocity should be less than -. 1 in. /sec. peak. The manufacturer of a compressor may select a velocity of 0. 5 in. /sec. peak, but the user may prefer to have the velocity kept to 0. 1 in. /sec. peak.

Here the manufacturer and the user have different criteria. The former is interested in producing machinery which will have a reasonable life and at the same time will be able to compete with other manufacturers. The latter is interested in machinery that will fit into his operation and at the same time be economical.

The extent of the vibration frequency spectrum which is of physiological significance can be divided into five fairly distinct bands (26):

1. 0. 1 to 1 c/s - Oscillations in this band can provide motion sickness if intense and sustained.

2. 1 to 30 c/s - This range (and especially the band 1 to 15 c/s) is of the greatest importance because it is the band in which the major resonances occur in the human body. It is also a band in which vibration isolation is technically difficult.

3. 30 to 100 c/s - This is above the band in which major body resonances occur, and blurring of vision can be an important symptom of whole body vibration in this range. Intense local vibration at frequencies in the same region creates the special industrial hazard of disease associated with handheld machine tools.

4. 100 to 20, 000 c/s - Broadly speaking, the audio-frequency range, in which vibration is strongly attenuated at the surface of the human body.

5. Above 20, 000 c/s - By definition, ultrasonic regime. Although ultrasonic vibrations transmitted by fluid or solid media can be biologically destructive, they are poorly propagated in air and are unlikely to be a serious hazard to man in most practical situations.

4.1 Vibration Exposure Criteria

The psychological effects like perception. feelings of discomfort. and pain have been studied by several investigators but the data available seem to be rather limited (27). The vibration exposure criteria curves have been proposed in the I. S. O. for the range 1 Hz to 100 Hz, for vibration transmitted to the torso of a person standing or sitting. The vibration levels indicated by the curves in terms of RMS acceleration levels which produce equal fatigue-decreased proficiency.

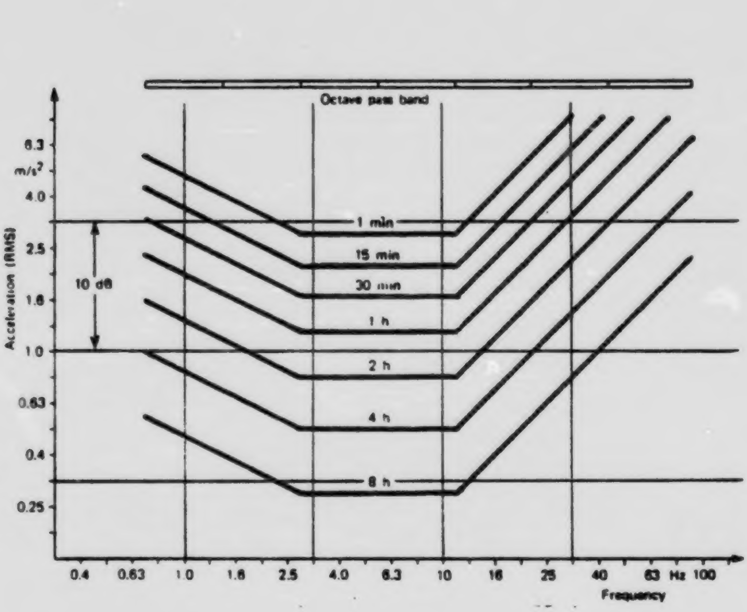


Figure 19: Vibration Exposure Criteria Curves.

These criteria are presented as recommended guidelines or trend curves rather than firm boundaries classifying quantitative biological or psychological limits. They are intended only for situations involving healthy, normal people considered fit for normal living routines and the stress of an average working day (ISO)

5. STANDARDS

The greatest opportunity for an engineer in the field of noise control should be the selection of equipment which has been designed to produce low noise levels. Unfortunately, the manufacture of such equipment is limited and, for most equipment groups, non-existent.

Much more is known about the general acoustic principles of noise control than about the application of these principles to specific noise sources. Some equipment manufacturers direct little effort toward noise reduction, while others direct considerable research effort to the design and development of quiet equipment. The progress has been made by them, but the progress is small in comparison to the increase in industrial noise. Acceptance by industry has been less than favorable because of increased costs. Manufacturers must be assured of a market for quiet equipment before the cost of research, design, or modification can be assumed. The demand for quiet equipment can be made known only by buyers incorporating noise control requirements in their engineering specifications.

At present, many equipment manufacturers will provide noise data upon request but before such data can be meaningful, the measurement procedure and room in which the tests are made must be clearly specified. A comparison of the data received from various manufacturers is impossible without such information.

The need for a unique thought about measure number and shape has led to the formation of standards wich have international or national importance.

5.1 International Standards

The object of international standardization is to set up a set of rules which facilitate the international exchange of goods and services and technological and economic activity. At present, two international bodies exist for international standardization: the International Electrotechnical Commission (IEC) and the International Organization for Standardization (ISO) (28).

A number of international recommendations related to the use of our measurements are summarized below.

5.1.1. International Electrotechnical Commission

IEC Recommendation, Publication 50 (08). International Electrotechnical Vocabulary, Electro-Acoustics (1960).

IEC Recommendation, Publication 118. Recommended Methods for Measurements of the Electro-Acoustical Characteristics of Hearing Aids (1959).

IEC Recommendation, Publication 123. Recommendations for Sound Level Meters (1961).

IEC Recommendation, Publication 179. Precision Sound Level Meters (1965).

IEC Recommendation, Publication 225. Octave, Half-Octave and Third-Octave Band Filters Intended for the Analysis of Sounds and Vibrations (1966).

IEC Recommendation, Publication 268-1. Sound System Equipment Part 1: General (1968)

IEC Recommendation, Publication 268-1A. First Supplement to Publication 268-1. Sound System Equipment. Part 1: General (1970).

IEC Recommendation, Publication 268.2. Sound System Equipment. Part 2: Explanation of General Terms (1971).

IEC Recommendation, Publication 268-3. Sound System Equipment. Part 3: Sound System Amplifiers (1969).

IEC Recommendation, Publication 268-3A. First Supplement to Publication 268-3. Sound System Equipment. Part 3: Sound System Amplifiers (1970)

IEC Recommendation, Publication 268-14. Sound System Equipment. Part 14: Mechanical Design Features (1971).

5.1.2 International Organization for Standardization

ISO Recommendation R31 Part VII. Quantities and Units of Acoustics (1965).
ISO Recommendation R131. Expression of the Physical and Subjective Magnitudes of Sound or Noise (1959).
ISO Recommendation R140. Field and Laboratory Measurements of Airborne and Impact Sound Transmission (1960).
ISO Recommendation R226. Normal Equal-Loudness Contours for Pure Tones and Normal Threshold of Hearing Under Free Field Listening Conditions (1962).
ISO Recommendation R266. Preferred Frequencies for Acoustical Measurements (1962).
ISO Recommendation R357 (Supplementary to R131). Expression of the Power and Intensity Levels of Sound or Noise (1963).
ISO Recommendation R362. Measurement of Noise Emitted by Vehicles (1964).
ISO Recommendation R495. General Requirements for the Preparation of Test Codes for Measuring the Noise Emitted by Machines (1966).
ISO Recommendation R512. Sound Signaling Devices on Motor Vehicles, Acoustic Standards and Technical Specifications (1966).
ISO Recommendation R532. Method for Calculating Loudness Level (1966).
ISO Recommendation R1680. Test Code for the Airborne Noise Emitted by Rotating Electrical Machinery (1970).
ISO Recommendation R1996. Acoustics, Assessment of Noise with Respect to Community Response (1971).
ISO Recommendation R1999. Acoustics, Assessment of Occupational Noise Exposure for Hearing Conservation Purposes (1971).
ISO Recommendation R2017. Vibration and shock-isolators-specifying characteristics (Guide for selecting and applying resilient devices)
ISO Recommendation R2041. Vibration and shock-Terminology.
ISO Recommendation R----. Test code for the measurement of sound from pneumatic equipment.

5.2 National Standards

Significant achievements have been made by several manufacturing groups in overcoming the confusion of noise measurement and data reporting. Standard methods for sound testing and data reporting have been developed by the Air Moving and Conditioning Association (29); the American Society of Heating, Refrigeration, and Air Conditioning Engineers, Inc. (30); the American Gear Manufacturers Association (31); the National Electrical Manufacturers Association (32); and the Institute of Electrical and Electronic Engineers (33) for their respective manufacturing groups.

Many equipment manufacturers have no standard methods for sound testing and data reporting.

Existing standards related to noise ratings, noise measurements, and noise tests are listed by title under the name of the organization or society using the standard.

American Gear Manufacturers Association

AGMA Standard 293. 03. Specification for Measurement of Sound on High Speed Helical and Herringbone Gear Units. (1968)

American National Standards Institute

ASA S1. 1-1960. American Standard Acoustical Terminology

ASA S1. 2-1962. American Standard Method for the Physical Measurement of Sound.

ANSI S1. 4-1971. American National Standard Specifications for Sound Level Meters

USAS S1. 6-1967. USA Standard Preferred Frequencies and Band Numbers for Acoustical Measurements

ANSI S1. 8-1969. American National Standard Preferred Reference Quantities for Acoustical Levels

ASA S1. 10-1966. American Standard Method for the Calibration of Microphones

ASA S1. 11-1966. American Standard Specification for Octave, Half-Octave, and Third-Octave Band Filter Sets

USAS S1. 12-1967. USA Standard Specifications for Laboratory Standard Microphones

ANSI S1. 13-1971. American National Standard Methods for the Measurement of Sound Pressure Levels

ASA S3. 1-1960. American Standard Criteria for Background Noise in Audiometer Rooms

ASA S3. 3-1960. American Standard Methods for Measurement of Electroacoustical Characteristics of Hearing Aids

USAS S3. 4-1968. USA Standard Procedure for the Computation of Loudness of Noise

ANSI S3. 6-1969. American National Standard Specifications for Audiometers

USAS S3. 8-1967. USA Standard Method of Expressing Hearing Aid Performance

ANSI S5. 1-1971. American National Standards Test Code for the Measurement of Sound from Pneumatic Equipment

ASA Y10-11-1963. American Standard Letter Symbols for Acoustics

ASA Z24. 9-1949. American Standard Method for the Coupler Calibration of Earphones

ASA Z24. 22-1957. American Standard Method for the Measurement of the Real-Ear Attenuation of Ear Protectors at Threshold

American Society of Heating, Refrigerating and Air-Conditioning Engineers

ASHRAE Standard 36-62. Measurement of Sound Power Radiated from Heating, Refrigerating and Air-Conditioning Equipment

ASHRAE Standard 36A-63. Method of Determining Sound Power Levels of Room Air Conditioners and Other Ductless, Through-The-Wall Equipment

ASHRAE Standard 36B-63. Method of Testing for Rating the Acoustic Performance of Air Control and Terminal Devices and Similar Equipment

American Society for Testing and Materials

ASTM Designation: C634-69. Standard Definitions of Terms Relating to Acoustical Tests of Building Constructions and Materials

Anti-Friction Bearing Manufacturers Association

AFBMA Standard No. 13. Rolling Bearing Vibration and Noise. (1968).

Association of Home Appliance Manufacturers

AHAM Standard SR-1. Room Air Conditioner Sound Rating. (1971)

Compressed Air and Gas Institute

CAGI Test Code. CAGI-PNEUROP Test Code for the Measurement of Sound from Penumatic Equipment. (1969)

Institute of Electrical and Electronic Engineers

IEEE No. 85. Test Procedure for Airborne Noise Measurements on Rotating Electric Machinery. (1965).

IEEE No. 151. Standard Definitions of Terms for Audio and Electroacoustics. (1965)

National Machine Tool Builders Association

NMTBA Standard. Noise Measurement Techniques. (1970)

Society of Automotive Engineers

SAE Standard J672a. Exterior Loudness Evaluation of Heavy Trucks and Buses. (1970)

SAE Recommended Practice J919. Measurement of Sound Level at Operator Station. (1966)

SAE Recommended Practice J919a. Sound Level Measurements at the Operator Station for Agricultural and Construction Equipment. (1971)

SAE Standard J952b. Sound Levels for Engine Powered Equipment. (1969)

SAE Recommended Practice J184. Qualifying a Sound Data Acquisition System. (1970)

SAE Recommended Practice J336. Sound Level for Truck Cab Interior. (1968)

SAE Recommended Practice J366. Exterior Sound Level for Heavy Trucks and Buses. (1969)

5.3 The Acoustical Design of an Anechoic Chamber and a Reverberation Room

The purpose of establishing standards for equipment noise measurement were:

1. to provide equipment noise data for use in the engineering design;
2. to provide a direct comparison of the noise levels of equipment built by different manufacturers;
3. to provide a method of direct comparison of noise levels of various types of equipment.

This method of noise measurement requires the use of a standard room and a calibrated reference sound source. The most commonly used sound source is a small modified fan.

The types of rooms or enclosures in which noise can be measured may be classified in three broad categories:

1. anechoic (echo-free) chambers;
2. reverberant (live) rooms; and
3. quiet (dead) rooms.

There are many combinations of these three, such as "convertible" rooms, "semi-anechoic rooms", "semi-reverberant", etc.

Table 9 is intended as a general guide towards the selection of the type of acoustic enclosure for each indicated usage (34).

TABLE 9

The Selection of Type of Acoustical Enclosure

Type of Use	Anechoic	Reverberant	Quiet
Directivity Patterns	Excellent	Poor	Good
Acoustic Power-Level	Poor	Excellent	Poor-Good
Pure Tone	Excellent	Poor-Good	Good
Free Field	Excellent	Poor	Poor-Good
Diffuse Field	Poor	Excellent	Poor
Reverberation	Poor	Excellent	Poor
High Intensity	Poor	Excellent	Poor-Good
Noise Generation "Machine" Enclosure	--	Poor	Excellent
Production Measuring Station	--	Excellent	Good-Excellent
Comparison Analysis	Excellent	Good-Excellent	Excellent
Control Booth	--	Poor	Excellent
Psycho-Acoustic Research	Excellent	Poor	Good-Excellent

For future investigations, two rooms were constructed with an initial measurement valve of 125 Hz.

The Anechoic Chamber (Figure 20) gives excellent data for directivity patterns. The reverberant room (Figure 21) gives better data in the diffuse field and for measurement of power levels. These constructions are composed elements and can be transported.

The dimensions of the anechoic room were chosen mainly with regard to the largest measuring distance to be used. Most sound measurements are made in the far field, because the interest is in the total sound radiated from the noise source. A good rule of thumb is that the microphone distance should be at least 3 to 4 diameters of the largest dimension of the radiating source. The measured power levels are in best agreement down to values of $r/a = 2$, where r is the radius of the test hemisphere and a is the maximum motor or machine dimension (35). In our case, $a = 0.8$ m, and
$r = 1.6$ m.

Another factor which influences room dimensions is the lower limiting frequency. This frequency is determined not only by the nature of the material covering the walls, but also by the ratio between room dimensions and wavelength. From the theory of sound transmission in heavily damped ducts we know that the condition for undisturbed sound transmission parallel to heavily damped surfaces is that:

$$\frac{h}{\lambda} > \frac{/z/}{1.2\,\rho.c} \qquad (16)$$

where: $\underline{h}$ is the width of the duct,
$\underline{\lambda}$ is the wavelength and
$\underline{z}$ is the acoustic impedance of the walls,
$\underline{\rho}$ is density of air, kg/m^3 and
$\underline{c}$ is speed of sound in air, m/sec.

The lower limiting frequency was chosen to be 120 Hz, which gives $h > 1.5$ m. As a result of all considerations, the free part of the smaller anechoic room was fixed at 4 x 3 x 2 m.

The volume of the reveration room is 217 m^3; the area of the enclosing surfaces is 220 m^3 (Figure 21).

The normal modes (eigen-frequencies) can be calculated from the parameters of the room sizes.

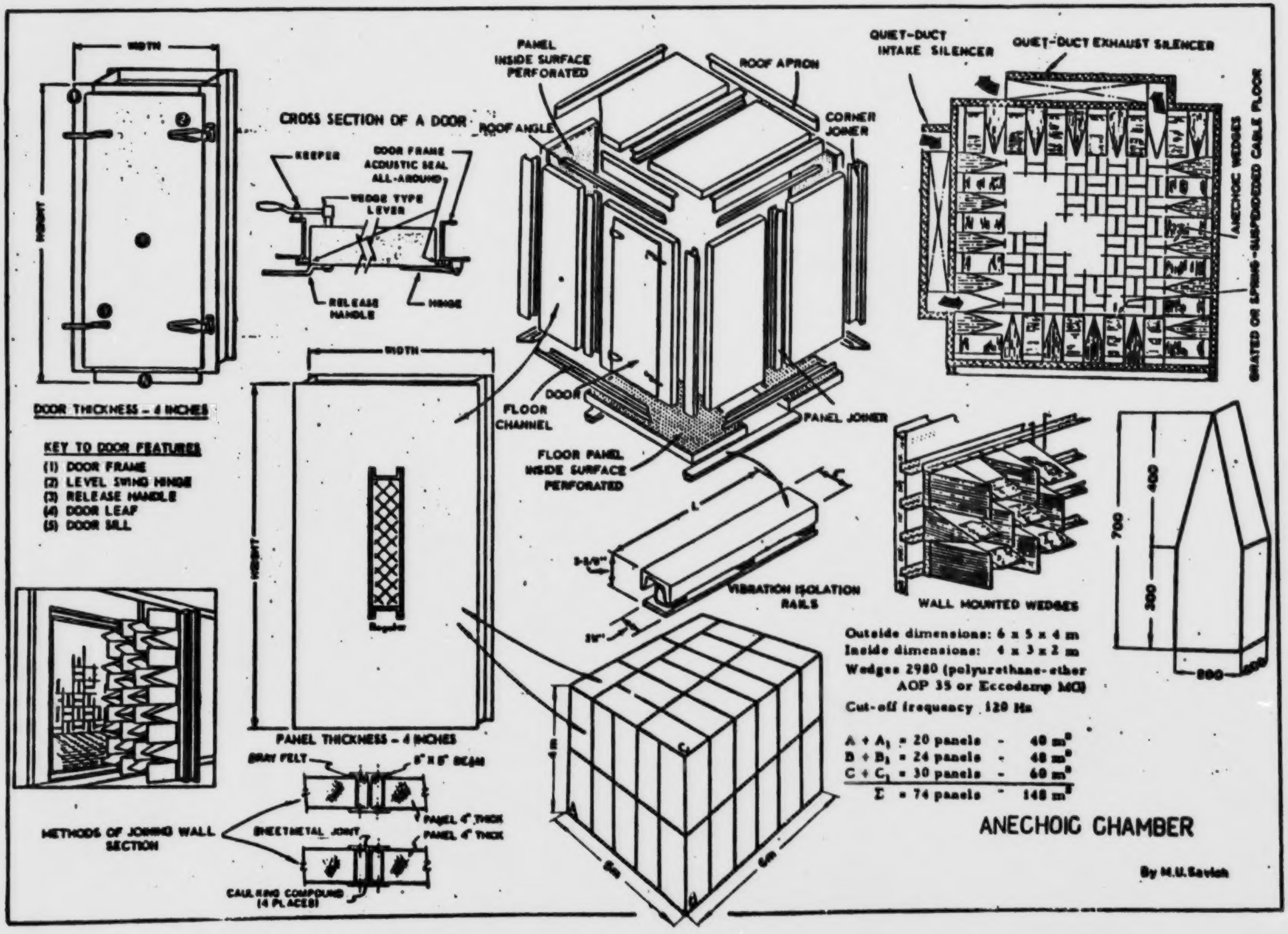

WIDTH
HEIGHT
DOOR THICKNESS - 4 INCHES
KEY TO DOOR FEATURES
(1) DOOR FRAME
(2) LEVEL SWING HINGE
(3) RELEASE HANDLE
(4) DOOR LEAF
(5) DOOR SILL
CROSS SECTION OF A DOOR
KEEPER
DOOR FRAME
ACOUSTIC SEAL
ALL-AROUND
WEDGE TYPE
LEVER
RELEASE
HANDLE
HINGE
PANEL THICKNESS - 4 INCHES
GRAY FELT
6" X 6" BEAM
PANEL 4" THICK
SHEETMETAL JOINT
PANEL 4" THICK
CAULKING COMPOUND
(4 PLACES)
METHODS OF JOINING WALL
SECTION
PANEL
INSIDE SURFACE
PERFORATED
ROOF APRON
ROOF ANGLE
CORNER
JOINER
DOOR
FLOOR
CHANNEL
PANEL JOINER
FLOOR PANEL
INSIDE SURFACE
PERFORATED
3-5/8"
VIBRATION ISOLATION
RAILS
5m
6m
4m
QUIET-DUCT
INTAKE SILENCER
QUIET-DUCT EXHAUST SILENCER
ANECHOIC WEDGES
GRATED OR SPRING-SUSPENDED CABLE FLOOR
WALL MOUNTED WEDGES
700
400
300
800
Outside dimensions: 6 x 5 x 4 m
Inside dimensions: 4 x 3 x 2 m
Wedges 2980 (polyurethane-ether
AOP 35 or Eccodamp MC)
Cut-off frequency 120 Hz
A + A₁ = 20 panels - 40 m²
B + B₁ = 24 panels - 48 m²
C + C₁ = 30 panels - 60 m²
Σ = 74 panels - 148 m²
ANECHOIC CHAMBER
By M.U.Savioh

Figure 20: Anechoic Chamber.

If L, W and H are the length, one may consider a rectangular room of equal volume ($7.23 \times 6 \times 5 \simeq 217 m^3$). The eigen-frequencies are obtained from the equation (36) (37):

$$f = \frac{c}{2}\sqrt{\left(\frac{p}{L}\right)^2 + \left(\frac{2}{W}\right)^2 + \left(\frac{h}{H}\right)^2} \qquad (17)$$

where c is the velocity of sound, and p, q, and r are in legers, including zero. According to the expression (38):

$$f_{lim} \sqrt[3]{V} \simeq 1000 \qquad (18)$$

The lowest frequency at which appropriate measurement conditions exist should be:

$$f_{lim} \simeq 166 \text{ Hz} \qquad (19)$$

In both cases the lower limiting frequencies are satisfactory.

Figure 21 is a sketch of the Swedish-built reverberation room. The roof has a step-like construction and is half as high and thus is cheaper.

According to the expression (39):

$$V \geqq 3\lambda^3_{lim}$$

should be:

$$\lambda_{lim} = \sqrt[3]{\frac{V}{3}} = \sqrt[3]{\frac{70}{3}} \approx 2.86 \text{ m; i.e. } f_{lim} \frac{c}{\lambda_{lim}} \approx 120 \text{ Hz}$$

The measurements were also made in the octave band centered at 63 Hz. Even though the spread in measured valves was larger than that obtained at higher frequencies, remarkably good results were achieved.

The acoustical design for a quiet room is not shown because, it is not useful in our research.

A detailed analysis will prove which type of room should be built; to have both is ideal.

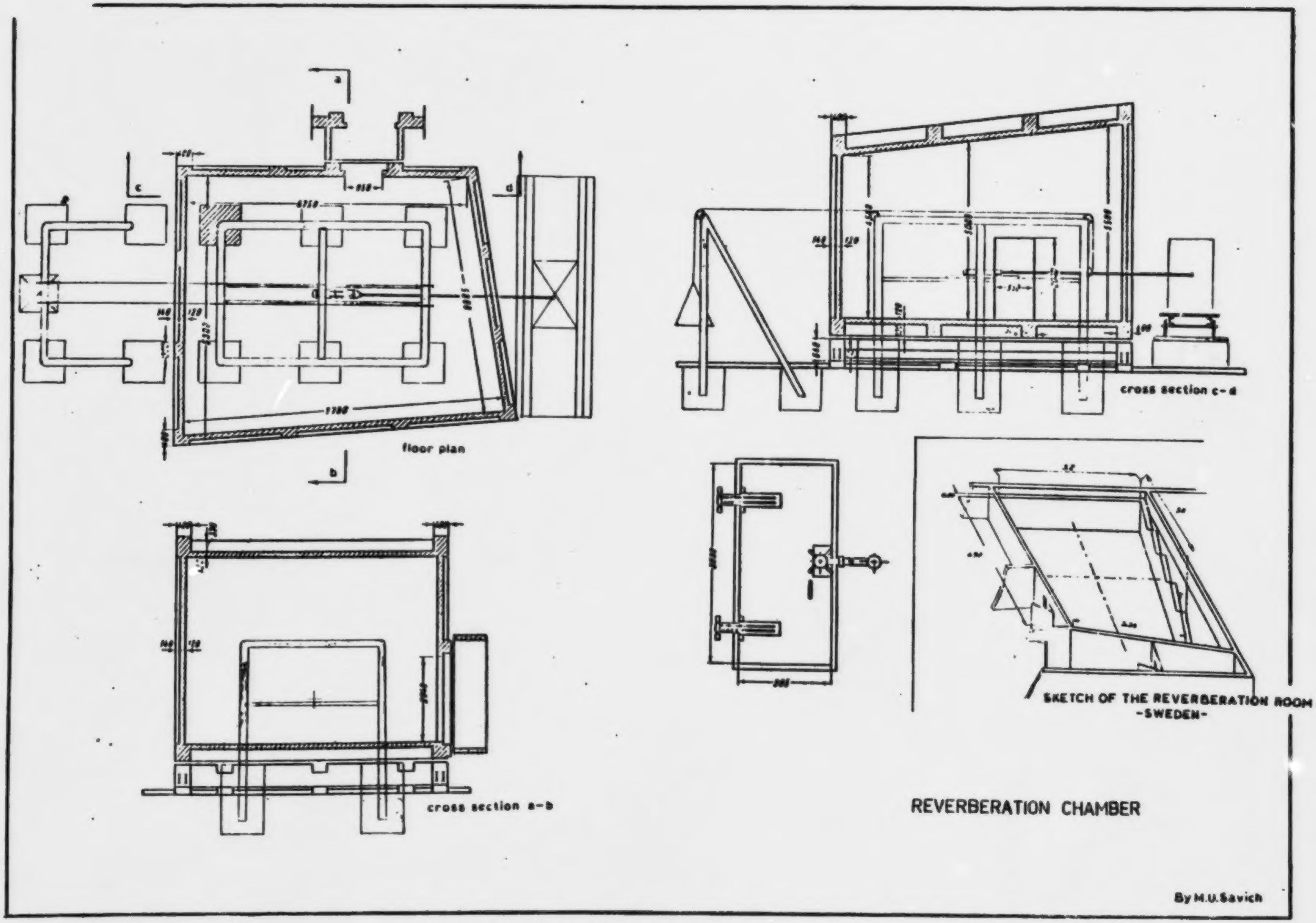

a
b
c
d
floor plan
cross section a-b
cross section c-d
140
120
SKETCH OF THE REVERBERATION ROOM
-SWEDEN-
REVERBERATION CHAMBER
By M.U.Savich

Figure 21: Reverberation Chamber.

An approximate calculation (G. Zahary and M.V. Savich) showed that the anechoic chamber is more expensive:

Anechoic Chamber ---------	$44,000.
Reverberation Chamber -----	$39,000

Basic research concentrates on reducing noise at its source, by isolating and measuring the noise from various machines. The elimination of machine noise at its source, which requires the virtual redesigning of machine systems and components, is the long range plan at the Mining Research Centre.

6. MAN AND THE ENVIRONMENT IN MINING

Many people feel that in achieving our technological and social progress, inadequate consideration was given to the "residues" of this progress upon man's total environment.

A mine and its ore treatment installations affect the environment directly and indirectly. It is directly affected by:

a) Construction: The mine, materials handling facilities, ore treatment, industrial plant for water supply and water cooling, waste treatment etc.

b) Emissions: Air pollution, water pollution, solid waste disposal, noise, vibration, radiation and light.

It is indirectly affected by:

a) Mine services: Roads, railroads, canals, port facilities, etc.

b) Community services: Town planning, housing, leisure activities, etc.

Table 10 suggests the degree in which the miner or man in a mining environment is affected.

In the past very little attention was paid to environmental aspects, whereas in the majority of new mining projects the influence on the environment has been solved.

TABLE 10

Effect of the Mine on Man and the Environment

Subject	Constructions	Emissions	Mine services	Community Services		Σ
Air	1	3	2	1		7
Water	1	3	2	2		8
Flora	2	3	1	1		7
Fauna	1	3	2	1		7
Man	2	2	3	3		10
Community	2	2	3	3		10

Degree of influence
1- None
2- Some
3- Large

Note: From this table we see that man and community are the most exposed to the influence of the environment.

6. 1 Effect of Noise and Vibration in Mine and Community Planning

When a mine is opened and a new community constructed, or an old one enlarged, many natural factors are important, e. g. wind direction, proximity of major communications, distance from the mine, the supply, etc. In planning a new community the site which has priority is one which satisfies the following conditions (two, three or more alternatives are chosen):

	Alternative A	Alternative B
Distance from mine to home	+	-
Dist. from home to major communication	-	+
Existing community	-	+
Water supply	-	+
Power supply	:	:
Pollution risk:	+	-
a) air (Clim. condition)	+	-
b) water	+	-
c) waste disposal	-	+
d) noise and vibration	+	-
Public transport	-	+
Forest, Lake, etc.	+	-
Total advantages	3	4
Total disadvantages	4	3

Alternative B has poor priority compared to alternative A, after factors are analyzed before the final decision is made. In this case the factor "Pollution risk" is characteristic. If the components of "Pollution risk" had the value of a factor, alternatives A and B would have equal chances.

It is a fact that surface transportation noise is one of the major sources of community noise. In Figure 22, Thiessen (40) depicts the noise produced by passenger cars, tractor trailers and motorcycles. The noise levels shown were measured at a distance of 50 feet.

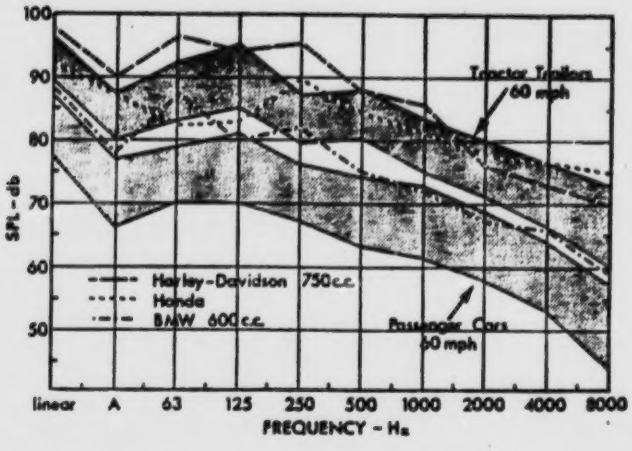


Figure 22: Measurement of Noise Produced by Tractor Trailers and Passenger Cars (40).

The spectra of motorcycle noise represent single vehicles. The levels are for throttle conditions which Thiessen states is the favorite condition in which these vehicles are used. Figure 23 is the spectral distribution of noise of trucks passing by in a 100-truck sample conducted by the Noise and Vibration Laboratory of the General Motors Corporation (41). The measurement location was 50 feet from the center of the near traffic lane and four feet above its surface. Both Figures 22 and 23 indicate the low frequency characteristic of the motor vehicle noise spectrum.

The passenger car can be relatively quiet in the community, provided the operator does not create undue tire whine or squeal by excessive acceleration, or turning at an excessive speed. This condition is found frequently in teenage dirvers. Aside from this, it is the great number of passenger cars that contributes to the community noise problem.

Measurements and discussions until now showed that components "Pollution risk" would have to be raised to the factor level. Every one of the components can permanently disrupt normal life development in the community. Noise (blasting, community noise) and vibration (blasting, land movements) can be of capital importance for the further development of the community (e. g., Asbestos Mines).

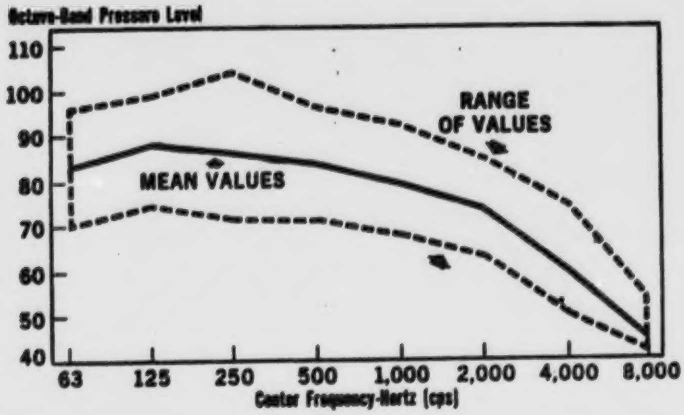


Figure 23: Measurement of Truck Noise.

6.2 Planning of the Ore Production and Handling Installation with Respect to Noise and Vibration

The location of a mining operation is determined by the location of the ore-body. It is very difficult to choose the best place for the deposition of slag and waste waters, and environmental qualities must be considered. If a solution cannot be found there, an appropriate location is sought for plant construction in the vicinity and the ore is transported.

In the construction of the pre-handling process and other installations, the following factors must be taken into consideration for the abatement of noise and vibration:

1. machines which produce high noise must be located out of communications;
2. noise could be reduced by the use of enclosures and vibration isolation;
3. machines should be chosen which produce less noise and have the same capacity;
4. isolation booths should be constructed for operators, if the noise surpasses the permissible limit;
5. impact protection systems should be built in where impact noise surpasses the permissible limit;
6. technological process should be chosen which produce less noise and vibrations but have the same capacity. In the aspect of the whole project, the other pollution components must be considered because some times they are more dangerous than noise and vibration.

The construction of roads, railroads, canal facilities, etc. are planned, if possible, out of the operative zone of the mine and the plant.

6.3 Planning Quiet Community Services and Rehabilitation Outside the Communication System

The town must be near a forest because it absorbs the noise. The railroad produces noise and vibration and cannot be in the centre of town. The houses must have noise and heat insulation (both isolations are casually tied together), as the temperature falls to - 25°C in most mining communities in Canada. The recreation centre should be projected near forest and water.

Elliot Lake can be considered one of the best community services in Canada and in the world. But it is true that nature played the greater part in the solution of this problem.

7. NOISE IN CANADIAN MINES

7.1 Coal Mines

North American petroleum and gas resources would be unable to meet continental requirements and Canadian coal would find its place.

In 1970, the Canadian coal industry increased sharply. There were large increases for lignite in Saskatchewan, subbituminous in Alberta, and bituminous coal in Alberta and British Columbia. Seventy-two per cent of all coal in Canada in 1970 was produced by surface mining methods and total coal production was 16.6 million short tons. Based on the growing demand for coal by domestic industry and for export purposes, it is reasonable to forecast that annual production will be 20 million short tons in the next decade (42).

Number of Employees

	Staff	Miners
Underground	603	4,754
Surface	162	1,390
Σ	765	6,144

The output per man-day from surface mines increased to 52.6 tons from 46.5 tons in 1969. In underground mines output increased to 4.9 tons from 3.6 tons in 1969.

Great mechanization was necessary to obtain such high efficiency.

Nova Scotia:

Underground: 3 mechanical loaders,
6 dragline, 6 to 14 cu yd,
6 loaders, 2 to 5 cu yd.

Saskatchewan:

Surface: 16 dragline, 6 cu yd to 35 cu yd
6 haulers, 20 tons to 50 tons
5 shovels, 3 3/4 cu yd to 20 cu yd
17 haulage, 40 to 70 tons

Alberta:

Underground: 25 continuous miners
14 mechanical loaders
34 shuttle cars
2 shearers

Surface: 3 bulldozers
18 shovels
5 loaders
55 haulage
3 drills
6 draglines
2 backhoes

British Columbia:

Underground: 1 mechanical loader
1 dragline
2 shovels

Surface: 27 trucks
5 drills

Cleaning Plants

1) Dry screening (with and without crushing)
2-800 to 850 tph
2-600 to 650 tph
4-150 to 200 tph
3- 50 to 100 tph
6- -- to 50 tph

3) Flotation
1-650 tph
1-400 tph
1-300 tph

2) Vibration Screens
3-300 tph
1-200 tph
1- 25 tph

4) Figure
1-385 tph
1-350 tph
1-200 tph
1-150 tph

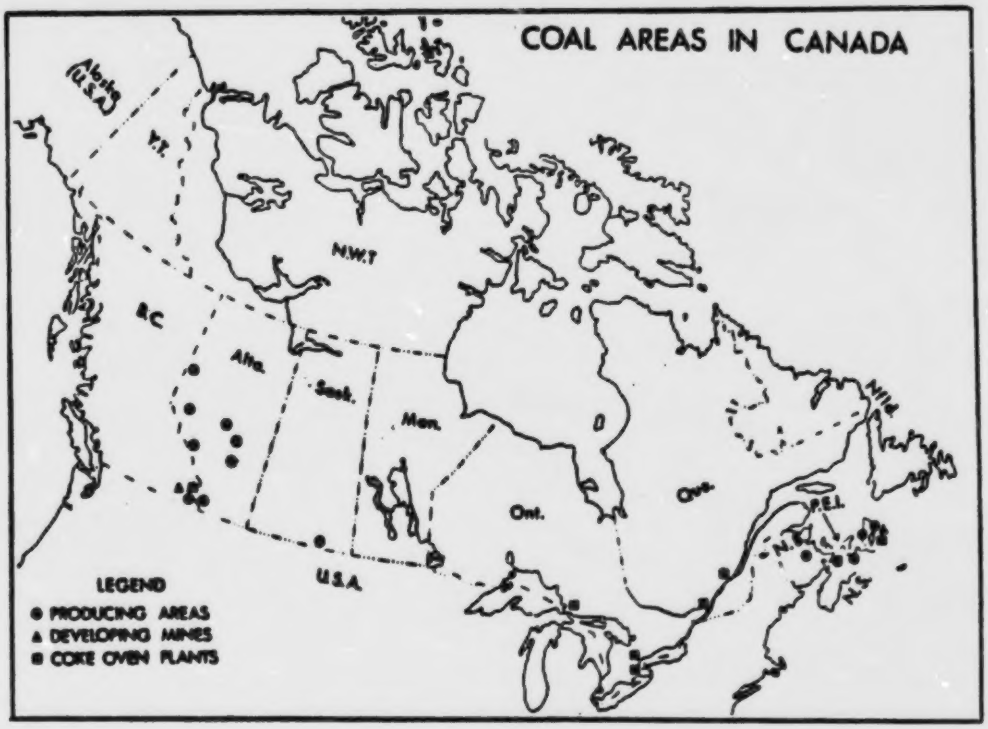

COAL AREAS IN CANADA
Alaska (U.S.A.)
Y.T.
N.W.T.
B.C.
Alta.
Sask.
Man.
Ont.
Que.
Nfld.
P.E.I.
N.B.
N.S.
U.S.A.
LEGEND
● PRODUCING AREAS
▲ DEVELOPING MINES
■ COKE OVEN PLANTS

Figure 24: Coal Mines in Canada.

From the data mentioned above, we see that in coal production high-capacity mechanization is mostly involved. This has resulted in a noise increase. Exploitation in Nova Scotia underground only and in Alberta mostly on surface.

The USA Bureau of Mines tested 21 mines in an environmental noise survey and the testing values are reported in the following tables.

Table 11 lists the sound level ranges for the occupations studied in underground coal mines (43) and Table 12 lists the average sound level measured at various work stations (44).

TABLE 11

Sound Level Ranges for Occupations in Underground Coal Mines

Occupation	Number Sampled	Operation	Sound Level, dBA	
			Mean*	Range
Man-trip	--	Man-trip	93	74-100
Pneumatic roof bolter	9	1 drill, drilling	112	104-118
		2 drills, drilling	112	107-118
		Tighten bolt	103	93-105
		Air on only	84	77- 94
Loading machine operator	8	Load	99	90-108
		Manoeuver	93	85- 97
		Tram	90	90- 98
Continuous miner operator	17	Cut and load	97	89-107
		Maneouver	89	83- 92
		Tram	88	82- 92
Rotary roof bolter	12	2 drills, drilling	97	92-101
		1 drill, drilling	95	85-106
		Tram	87	80- 91
		Idle	87	84- 96
Cutting machine operator	5	Sump	96	93- 98
		Shear	94	85-103
		Undercut	92	85- 99
		Tram	86	80- 94
Coal drill operator	3	Drill	94	80-104
Shuttle car operator	8	Loading	93	90- 98
		Dumping	88	84- 94
		Tramming	87	85- 92

* "Mean" is the mean of the samples

TABLE 12

The Average Sound Level at Various Work Stations in Coal Cleaning Plants

Work Station	Sound Level dB(A)
Crusher and belt dump	96
Vibrator w/o coal	104
w/ coal	98
Crusher w/o coal	103
w/ coal	103
Tripper w/o coal	83
w/ coal	88
Control station	86
Raw coal tripper	87
Primary heavy media	97
Screen feeds	91
Vibrating feeds	109
Fine coal feeds	89
Railroad car rotary dump	86

If we compare these two tables with the data of labor force and mechanization in Canada, we can conclude that most of the workers are in the unpermissible noise level range. The situation becomes worse if we apply the limit of 85 dBA.

The data of the German literature are mostly in concordance with the data of the Bureau of Mines.

7.2 Metallic and Non-Metallic Mines

An analysis of the underground labor distribution in 82 mines was performed (45) (See Appendix). The working places were compared with the measurement data from MAPAO (46), data from the literature (9, 47, 48, 49, 50) and with personal observations and measurements. A summary table was drawn and it was calculated that out of 12,015 workers, 7,393 or 61% were exposed to noise. In the metallics underground mines in Canada there are 27,000 workers. It can be supposed that the percentage of workers which are exposed to the unpermissible noise level would be the same, about 16,000.

From the data in the Appendix, it can be seen that in gold mines a higher percentage of miners are exposed to the unpermissible noise level.

This is because of the great of hammer drills. Small -or medium - size hammer drills are the most dangerous sources of noise in mines (113-126 dBA).

It is hard to say whether mechanization reduces or increases noise because no analysis has been done in Canada; the measurements for analysis have not been taken. The measurements made by INCO and Falconbridge in Sudbury and by Cominco in British Columbia were limited mostly to noise of machines and were not of the permissible noise exposures of miners.

The evaluation of permissible noise exposures involved 87 mills and showed that 70. 16% of the workers are exposed to noise. This evaluation would be useful if we suppose that the workers do not change their position during work, i. e. if they move away from the machines. The process is mechanized and the workers' presence is not always necessary.

It is not possible to make a good evaluation without measurements because it depends upon the mills technology,capacity, etc. It is possible that the evaluation is high because Canadian mills are modern and large and thus the noise level is low. The Plant Force Report (Mechanical, Electrical, surface) is related mostly to the iron mines and a summary is given in the Canadian Mining Manual 1971 as shown in Table 13.

The evaluation was performed by a cautions analysis and it was found out that 29% of workers could be overexposed. It is possible that this evaluation corresponds to reality.

In the 1971 Canadian Mining Manual the survey of mechanization in 68 Mines Surface Plants is given. In the new 1972 Canadian Mining Manual there is no great differences in statistical data (72 mines). To date, six major pieces of equipment have been purchased according to the rigid noise requirements: three large haulage trucks, 45-50 ton, 60-65 ton and 85-100 ton; a shovel, a front-end leader and a jumbo drill.

The analysis of the haulage and shovel mechanization was performed. From the diagrams in Figure 25 we see that in haulage mostly 45 and 50 ton dumpers are used, and 4. 5 and 6 cu yd shovels (Figure 26). The data for the main types of vehicles of 85. 5, 70, 90, 110 and 150 tons were requested from TEREX GM, to establish the noise for different types of dumpers (51). From the data we see that with the increase of dimensions the noise at the right side, left side and rear is increased. The noise at the operator's station (ear) and on the front remains practically the same (Figure 27).

TABLE 13

Underground Labor Distribution

	Copper Mines	Gold Mines	Silver Mines	Zinc Mines	Lead Mines	Uranium Mines	Iron Ore Mines	Nickel Mines	Molybdenum Mines	Other Metals Mines	Nonmetals Mines	Total Mines	Exposed in %	Number of Exposed
STAFF														
U/G Supt.	28	15	8	6	5	3	2	7	2	4	4	84	--	--
Captains	42	30	5	10	11	10	1	--	3	1	3	116	20	23
Foremen	30	13	--	1	3	2	6	3	3	--	11	72	60	43
Shift bosses	199	103	24	31	41	67	22	30	11	10	6	544	80	435
Geologists	27	21	11	6	7	13	4	6	4	3	1	103	20	21
Samplers	23	28	4	4	4	10	3	--	1	--	1	78	40	31
Engineers	75	52	16	19	31	64	12	11	9	3	5	297	10	30
Safety	19	13	1	10	1	8	3	4	2	1	1	63	30	19
TOTAL STAFF	443	275	70	87	103	177	53	61	35	22	32	1,358	~40	602
STOPING														
Stope Bosses	112	30	--	--	5	--	4	--	--	--	--	151	80	121
Drillers, helpers	998	855	177	135	131	186	9	50	58	46	2	2,647	100	2,647
Timbermen, helpers	159	114	22	33	45	9	--	11	28	--	--	421	20	84
Scalers, rockbolters	65	--	--	--	2	50	2	--	1	2	1	123	30	40
Blasters, Loaders	80	10	4	12	28	4	25	22	--	6	3	194	70	2
Fill Men	16	26	--	8	4	5	--	--	--	--	--	59	30	18
Slushermen	134	113	14	18	27	78	14	3	16	--	27	444	30	133
Loader Operators	53	27	9	2	16	--	10	56	6	3	2	184	100	184
Haulage Operators	48	63	6	3	8	--	4	12	23	--	5	172	100	172
Muckers	26	15	4	--	--	--	--	--	23	--	1	69	10	7
Other	45	28	--	5	18	18	10	3	--	1	1	129	10	13
TOTAL STOPING	1736	1281	236	215	284	350	78	157	155	58	42	4,593	~74	3,421

	Copper Mines	Gold Mines	Silver Mines	Zinc Mines	Lead Mines	Uranium Mines	Iron Ore Mines	Nickel Mines	Molybdenum Mines	Other Metals Mines	Nonmetals Mines	Total Mines	Exposed in %	Number of Exposed
DEVELOPMENT														
Leaders	45	--	--	15	8	--	6	--	--	---	--	74	--	--
Drillers, Drifting	292	62	34	52	126	96	39	50	14	26	51	842	100	842
Drillers, Raising	96	52	15	22	44	36	34	27	6	4	--	336	100	336
Timbermen	78	49	--	18	14	22	5	--	--	4	--	190	40	76
Loader Operators	16	2	4	6	15	--	13	3	5	--	--	64	100	64
Slushermen	--	1	1	--	2	25	--	--	--	--	--	29	30	9
Haulage Operators	12	2	--	9	2	--	--	2	--	--	9	36	100	36
Muckers	11	9	2	3	2	--	5	--	4	2	--	38	10	4
Motor Crew	2	6	5	4	2	--	5	--	6	--	--	30	100	30
Other	111	1	--	16	6	8	2	3	--	--	31	178	10	18
Other	8	--	--	6	8	--	12	12	--	--	14	60	10	6
TOTAL DEVELOPMENT	671	184	61	151	229	187	121	97	35	36	105	1,877	~76	1,421
HAULAGE, HOISTING														
Loader Operators	140	79	10	--	9	18	6	--	5	12	--	279	100	279
Motormen	208	175	24	20	33	20	4	13	19	1	6	523	100	523
Switchmen	3	--	3	--	12	--	--	--	--	--	--	18	60	11
Chute Pullers	86	72	9	5	11	41	--	8	19	--	--	251	20	50
Dispatcher	7	--	--	--	--	--	--	--	--	--	--	7	--	--
Ore, Waste Pass	4	5	--	--	6	8	3	--	--	--	--	26	50	13
Crushermen	35	13	10	5	13	4	7	11	--	5	13	116	100	116
Skip Tenders	64	62	--	20	16	11	3	6	7	1	--	190	80	152
Cage Tenders	98	53	32	11	19	13	9	14	--	4	13	266	80	181
Top Men	62	21	19	12	9	13	--	1	4	--	3	144	50	72
Hoistmen	84	55	23	12	23	17	4	19	6	6	21	272	95	256
Other	24	4	--	--	7	9	1	22	12	7	4	90	10	9
TOTAL Haulage AND HOISTING	815	539	130	85	158	154	37	94	72	36	60	2,180	~76	1,662

	Copper Mines	Gold Mines	Silver Mines	Zinc Mines	Lead Mines	Uranium Mines	Iron Ore Mines	Nickel Mines	Molybdenum Mines	Other Metals Mines	Nonmetals Mines	Total Mines	Exposed in%	Number of Exposed
GENERAL														
Pipe Fitters	44	61	4	13	2	22	1	--	2	2	1	152	10	15
Trackmen	72	29	4	7	5	17	1	2	8	1	1	147	10	15
Pumpmen	14	3	2	--	4	2	1	--	1	--	4	31	75	23
Ventilation Crew	19	3	--	2	--	16	--	--	--	--	--	40	90	36
Warehousemen	20	22	1	--	--	3	1	--	--	--	--	47	--	--
Lampmen	25	11	3	2	4	9	2	2	2	1	1	62	--	--
Riggers	14	3	--	--	--	9	--	--	--	--	--	26	--	--
Fill Preparation	11	18	--	11	4	7	--	--	2	--	--	53	--	--
General Labor	173	22	3	18	118	13	9	--	2	1	64	423	--	--
Mechanics	174	41	18	26	27	92	35	28	6	--	13	460	10	46
Electricians	57	18	9	8	9	42	5	10	6	--	5	169	5	8
Steel, bit grinders	14	7	5	10	2	2	2	2	3	1	2	50	50	25
Exploration drillers	41	32	10	12	13	2	--	33	4	4	2	153	100	153
Other	39	32	3	8	7	14	3	2	--	1	4	113	--	--
Other	40	36	--	4	5	16	3	6	--	2	4	116	--	--
TOTAL GENERAL	760	338	62	121	199	266	63	85	36	13	101	2,044	16	321
TOTAL MINE	4,425	2,617	559	659	973	1,134	352	494	333	165	340	12,051	~62	7,427

Data - 82 Mines: Gold Mines (16), Silver Mines (10), Uranium and Thorium Mines (3), Copper Mines (27), Lead Mines (5), Iron Ore Mines (2), Nickel Mines (4), Zinc Mines (6), Molybdenum Mines (3), Other Metals Mines (3), Nonmetals Mines (3).

TABLE 14

Mill Force Report

			Exposed in %	Number of Exposed
STAFF	Superintendent, Assistant	105	--	--
	Foremen	116	50	58
	Shift bosses	242	10	24
	Metallurgists, (Chemists)	77	--	--
	Mill Engineer	31	70	21
	Chief Assayer, Assistant	115	100	115
	Clerk, Typists	60	20	12
	Mech. Maint. foremen	87	30	26
	Other	68	20	~14
	Other	15	20	3
	TOTAL STAFF	916	29.8	273
HOURLY RATED	Grinding, operators, helpers	403	100	403
	Crusher operators, helpers	469	100	469
	Flotation operators, helpers	318	100	318
	Conveyor operators	51	80	41
	Filter operators	131	50	65
	Solution men	106	20	21
	Taillings disposal	95	--	--
	Drying	105	40	42
	Sampling	124	90	113
	Assaying	223	100	223
	Gen'l. operators, helpers, labor	719	80	575
	Mechanical maintenance	714	80	571
	Electrical maintenance	81	30	~ 24
	Amalgamators	2	100	2
	Roaster operator, helper	36	10	~ 4
	Utility	28	50	14
	Backfill plant	25	50	~13
	Reagent men	36	50	18
	Other	78	50	39
	Other	74	50	37
	TOTAL CREW	3,818	80.25	2,992
	TOTAL EMPLOYEES IN DEPT.	4,734	~70	3,265

Data: 87 mills

TABLE 15

Plant Force Report (Mechanical, Electrical, Surface)

			Exposed in %	Number of Exposed
STAFF	Plant Superintendent	61	--	--
	Master Mechanic	77	--	--
	Chief Electrician	75	--	--
	Surface Superintendent	52	--	--
	Foremen, Shops, maint,	473	10	47
	Engineers	120	--	--
	Secretary, Clerks	92	10	~ 9
	Warehousemen	73	--	--
	Construction supervisor	19	20	~ 4
	Other	67	--	--
	Other	34	--	--
	TOTAL STAFF	1, 143	5. 2	60
HOURLY RATED	Power house, steam plant	266	--	--
	Machine shop, tradesmen	483	--	--
	Mechanics, helpers	1, 641	30	492
	Welders, helpers	530	50	265
	Blacksmiths	72	100	72
	Riggers	122	10	~12
	Pipefitters, plumbers	158	10	~16
	Drill steel, bits	52	10	~ 5
	Drill repair	69	10	~ 7
	Plate shop	92	80	~73
	Vulcanizing	39	--	--
	Electricians	753	20	152
	Carpenters	352	35	~126
	Painters	61	--	--
	Construction workers	49	50	~ 25
	Mobile equipment operators	481	90	432
	Hoistmen	248	80	198
	Compressormen	86	100	86
	Labourers	544	20	110
	Other	143	--	--
	TOTAL PLANT CREW	6, 241	33. 2	2, 071
	TOTAL SURFACE PLANT	7, 384	~28. 8	2, 121

TABLE 16

Force Report (Offices, General)

			Exposed in %	Number of Exposed
STAFF HOURLY PAID	Engineering	688	--	--
	Geological	216	20	~ 43
	Office Managers	54	--	--
	Accounting	436	--	--
	Purchasing	132	--	--
	Warehouse	429	--	--
	Security	189	--	--
	Personnel	127	--	--
	First Aid, Safety	138	--	--
	Secretarial, receptionist	168	10	~ 16
	Drymen	76	--	--
	Janitors	147	--	--
	Watchmen	45	--	--
	Gardners	19	--	--
	Clerks	79	--	--
	Other	775	--	--
	Other	154	--	--
	Other	19	--	--
	Other	24	--	--
	TOTAL	3, 310	~ 1.8	59

Total Mill, Plant and Force Report

Mill	4, 734	70	3, 265
Force	7, 384	28.8	2, 071
Staff	3, 310	1.8	59
Σ	15, 428	~35	5, 395

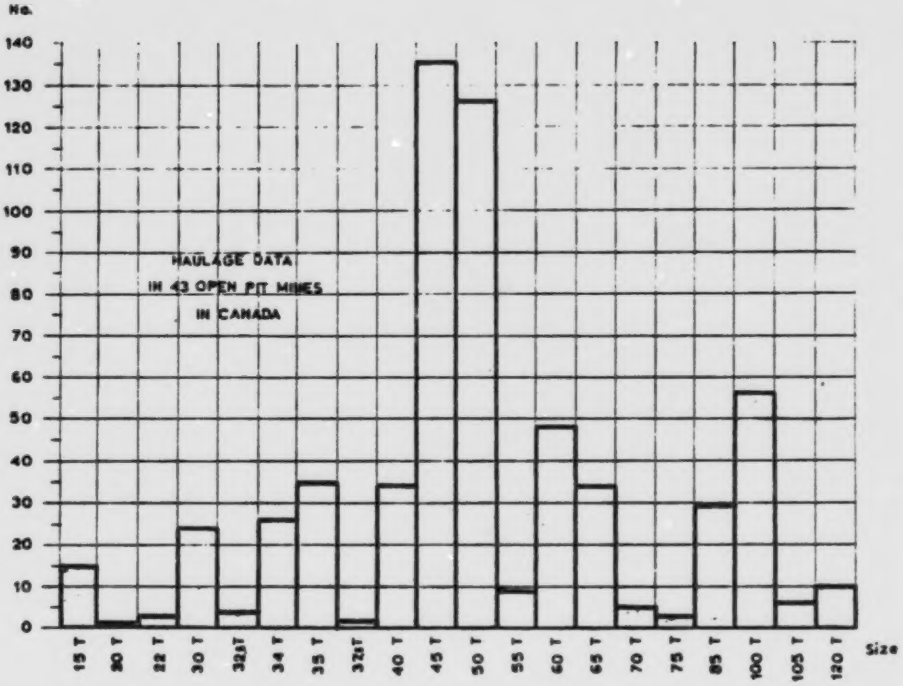


Figure 25: Haulage Data in Canadian Open Pit Mines.

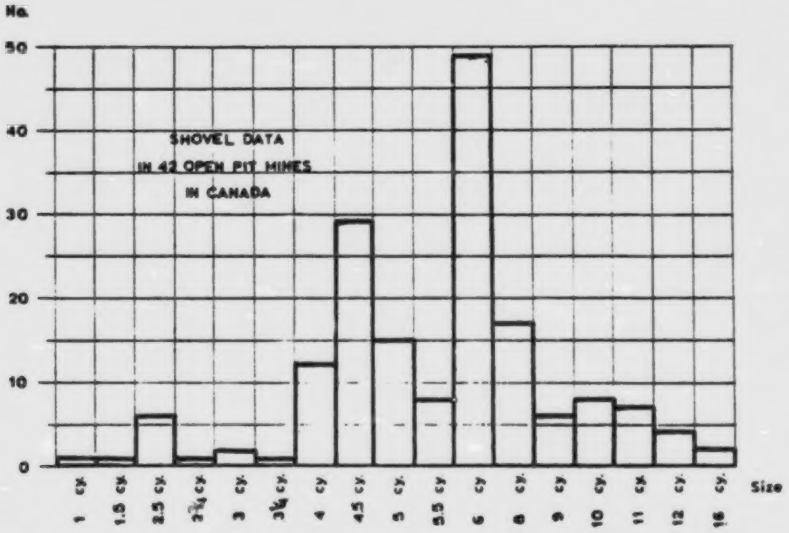


Figure 26: Shovel Data in Canadian Open Pit Mines.

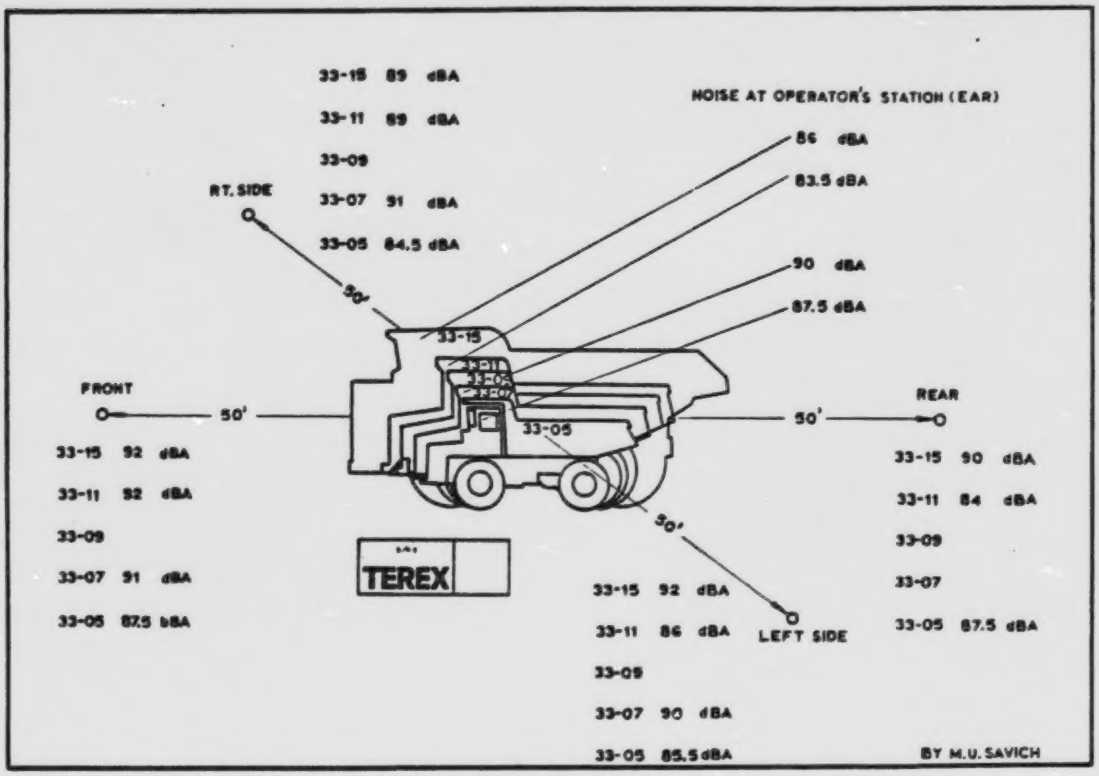

33-15 89 dBA
33-11 89 dBA
33-09
33-07 91 dBA
33-05 84.5 dBA
RT. SIDE
50'
NOISE AT OPERATOR'S STATION (EAR)
86 dBA
83.5 dBA
90 dBA
87.5 dBA
33-15
33-05
FRONT
50'
33-15 92 dBA
33-11 92 dBA
33-09
33-07 91 dBA
33-05 87.5 bBA
TEREX
50'
33-15 92 dBA
33-11 86 dBA
33-09
33-07 90 dBA
33-05 85.5 dBA
LEFT SIDE
REAR
50'
33-15 90 dBA
33-11 84 dBA
33-09
33-07
33-05 87.5 dBA
BY M.U. SAVICH

Figure 27: Sound Levels Pertaining to TEREX Haulers.

Readings were taken outside the cab along the centreline of the vehicles from the edge of the structure of the units.

These readings were taken at wide open throttle (W. O. T.) with windows closed and with bodies in the down position. The readings are based on tests on one of each vehicle and readings on subsequent vehicles could vary.

The 33 - 15 150 ton diesel-electric hauler manufactured in Canada has the following sound level data:

Octave Band Centre Frequency	Windows Closed		Windows Open	
	Idle	W. O. T.	Idle	W. O. T.
31.5 Hz	84dB	91dB	91dB	105dB
63 Hz	92dB	81dB	90dB	99dB
125 Hz	84dB	81dB	91dB	105dB
250 Hz	78dB	95dB	85dB	98dB
500 Hz	68dB	87dB	78dB	96dB
1000 Hz	66dB	80dB	78dB	93dB
2000 Hz	64dB	79dB	71dB	87dB
4000 Hz	61dB	73dB	64dB	79dB
8000 Hz	47dB	67dB	53dB	72dB
O/A	95dB	99.9dB	96dB	109dB
A Weighting	75dBA	86dBA	84dBA	97dBA
B Weighting	86dBB	94dBB	89dBB	102dBB
C Weighting	92dBC	97dBC	94dBC	106dBC

Noise from haulers, shovels and jumbo drills is one of the most disturbing problems in open pit mines we face today. With some 1.8 million trucks in operation on the highway, truck tire noise in Canada becomes a major environmental problem.

This year several useful articles concerning noise problems were published. In the Canadian Mining Journal, R. M. Borland described the noise suppression in trucks in Marmoraton Mining Company (52). "The present truck fleet illustrates that if the buyer insists that noise levels cannot be above allowable levels and that the measures used to obtain this must be lasting, the manufacturer can provide a satisfactory product."

In 1961, R. A. Morissette began to work on the construction of mufflers at diamond drills (53). This was a simple reactive muffler which reduced the noise for 4-5dB. N. Morissette Diamond Drilling Limited has continued the work on construction but mostly using empirical experiences. New mufflers accomplish noise reduction by combining absorptive and reactive effects (54).

J. E. Galmusky, Design Engineer, Joy Manufacturing Company, Galt constructed the muffler for the hammer drill, Joy AL-60 Air Leg (55). The construction is simple and can still be improved. Also, J. W. Reynolds constructed a rubber muffler of high efficiency, but at temperatures below freezing, the muffler is no more efficient.

At the last MAPAO meeting in Toronto, May 18, 1972, there were more lectures about noise but treated from the practical point of view, e. g. enclosures, muffled fans, audiometric testing, etc. (56, 57, 58, 59, 60, 61). Nine lectures were presented there, whereas in the past, only eight papers on noise in mining had been presented in Canada.

These works indicate a positive tendency in the fight against noise in mines and mills. Noise suppression at grinding mills in Midland, Ontario was made to assist in the design of Cominco Limited (62).

There is no noise problem in non-metallic mines. In the large potash mines of Saskatchewan, there are usually one or two continuous miners and their noise level is 94-96 dBA. The mill processing is a chemical-technological process involving no noise.

In the other non-metallic mines, gypsum, salt, etc., the situation is similar. Only in stone mines (granite and limestone) is the noise level so high that it becomes extremely dangerous.

7.3 Application of Noise and Vibration in Canadian Mines

In Canada there are qualified manufacturers which can help in noise reduction with their materials and designs.

1. Cominco Ltd. (Noise Control Products), Oakville, Ontario, Canada.
2. Foamade Industries (Canada) Ltd., Toronto, Ontario.
3. Good Year Canada Ltd., Toronto, Ontario.
4. Armstrong Co., Toronto, Ontario.
5. Tenace Tools Ltd., Toronto, Ontario.

A great number of mines bought the sound level meter (dBA), but do not use it for the following reasons:

- there are no instructions, recommendations or standards;
- there is no employee responsible;
- they are not familiar with the technique of measuring noise and vibration.

8. ENGINEERING CONTROL

8.1 Industrial Noise Control

Industrial noise control consists of the following (63):

I. Plant Planning

II. Substitution
  A. Use quieter equipment
  B. Use quieter process
  C. Use quieter material

III. Modification of the Noise Source
  A. Reduce driving force on vibrating surface
    1. Maintain dynamic balance
    2. Minimize rotational speed
    3. Increase duration of work cycle
    4. Decouple the driving force

  B. Reduce response of vibrating surface
    1. Add damping
    2. Improve bracing
    3. Increase stiffness
    4. Increase mass
    5. Shift resonant frequencies

  C. Reduce area of vibrating surface
    1. Reduce overall dimensions
    2. Perforate surface

  D. Use direction of source to advantage

  E. Reduce velocity of fluid flow

  F. Reduce turbulence

IV. Modification of the Sound Wave
    A. Confine the sound wave

    B. Absorb the sound wave
        1. Absorb sound within the room
        2. Absorb sound along its transmission path

    C. Use resonance phenomenon

In order for a miner to protect himself from noise, it is necessary that additional protective elements from noise and vibrations become part of every project, as well as having protective measures over the hearing organs.

If the noise level existing in the working area is produced by a number of individual noise sources, and this level must be reduced, it is essential to attack the individual sources in the order of their contribution to the total noise level. To control individual sources in a random fashion is to invite waste of time, effort and money.

Noise control is generally an expensive proposition that requires an appreciable amount of engineering time and talent. Sometimes, in spite of one's best efforts, one finds that it is either impossible or impractical to reduce the sound output of primary noise producers.

Power level data on new equipment can often be obtained from the equipment manufacturer. For equipment already installed in the plant, pressure level measurements taken around the equipment can be used to estimate its acoustical power. The procedure used for this field method is to take the measurements at specific points on an imaginery hemisphere having the noise source as its centre. The sound power of the source is calculated from the average of the measured pressure levels. Detailed procedures for the determination of sound power level from sound pressure level measurements are available from several sources (64, 65).

When the noise control engineer has learned all he can about the noise source, he must then choose and execute the method or methods showing the best promise under the existing environmental and operating conditions.

Plant Planning

The first opportunity one has in practising noise control engineering is in the planning of a new installation. It is usually easier and less expensive to prevent potential noise problems than to eliminate existing ones.

With a noise problem anticipated, control features can be included in the construction and layout. Individual machines can be placed so as to minimize worker exposure; massive partitions, vibration isolation and acoustical wall and ceiling treatment can be made a part of the original construction; and inherently noisy departments can be isolated from the quieter areas (e. g., the mill plant: crushers and ball mills).

Another aspect of planning is ordering equipment to noise specifications. This can be done by the purchaser specifying quiet equipment, especially if the manufacturers know that the purchasers are willing to pay for this type of noise control.

Substitution

Noise control can also be accomplished by substitution of equipment, processes or materials. Noise reduction may be accomplished simply by a judicious choice of equipment. One should not be too hasty in rejecting the quiet equipment that has the apparent disadvantage of high price. In the long run, the low-cost, noisier item may prove to be much costlier if it eventually requires noise control.

Examples of equipment substitution are:

1. turbines or belts for gear drives;
2. spiral or helical gears for spur gears;
3. mechanical for air ejection;
4. muffled pneumatic tools for unmuffled ones.

Quieter processes can sometimes be substituted for noisy ones. A well-known substitution of this sort is welding and riveting. Grinding, flame-gouging or arc-cutting can sometimes be used to remove excess metal in place of the noisy chipping or sawing method.

The substitution of quieter materials used in noise control. In order to reduce the noise generated from surfaces subjected to impact, it is always well to use materials having high internal damping which have less tendency to ring when struck. Rubber wheels are rolls are quieter than metal ones. Plastic gears are quieter than metal ones.

Modification of the Noise Source

There are many ways whereby the noise source can be modified to reduce the overall noise level that it generates. Forces that drive a noise-producing component often can be reduced with a resulting quieter operation. Imbalanced rotating or reciprocating machinery is capable of consuming a considerable amount of energy that often manifests itself as noise. If equipment is kept in balance, the non-productive acoustical energy will be minimized.

Minimizing the speed at which machinery operates is another method of reducing the driving forces with a corresponding reduction of noise levels. In some cases, it may be possible to spread the total expended energy required for a job over a longer period of time.

Where noise is a direct result of applying the necessary energy to the part being worked (e. g., drop hammer forging) there is little that can be done to the radiating source to significantly attenuate the noise level. The mechanical energy it receives and transforms into acoustical energy may be received incidentally, In such cases, it becomes possible to isolate the driving force from the noise radiator and thereby eliminate the noise.

Even if it is not possible to isolate the driving force responsible for the generation of noise, it still may be possible to modify the component driven by that force and accomplish the same end. That is, we can reduce the noise level by reducing the vibration of the noise radiator.

Another way to control the vibration of panels, under either resonant or non-resonant conditions, is to provide adequate support to the panel. Changing the mass or the stiffness of a vibrating component can also reduce its capability to generate noise.

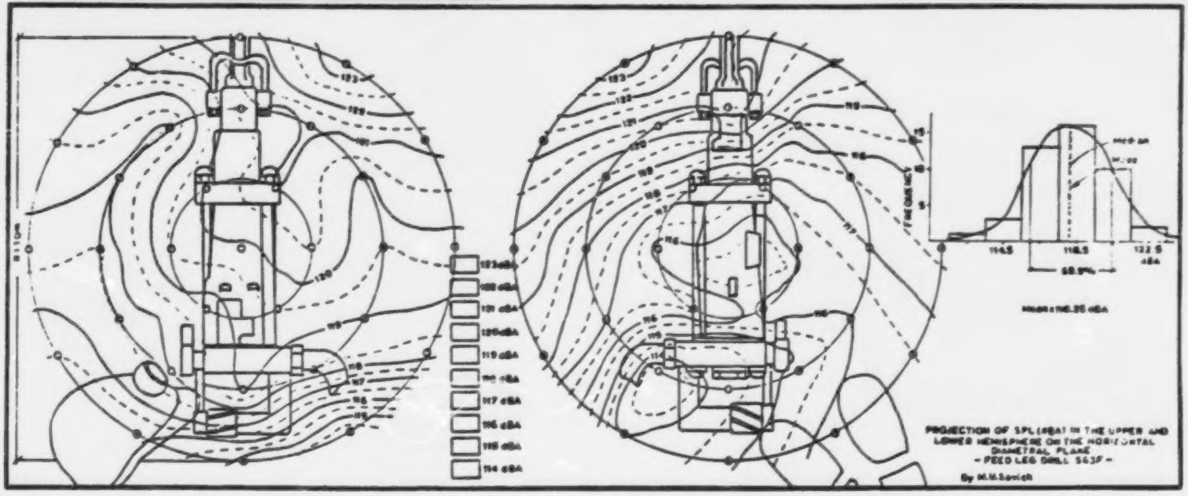
The noise generated by a vibrating panel is dependent not only upon its motion but also on its surface area; therefore, noise reduction is possible by reducing the surface area of the vibrating panel. Often the substitution of perforated or expanded metal panels for solid ones can accomplish significant noise reductions.

To a greater or lesser extent, most noise sources are directional. That is, they tend to radiate a greater amount of noise in one direction than another. Advantage should be taken of this property, especially with sources that are highly directional, to accomplish significant noise reductions. For example, a jet engine is highly directional, the hammer drill is also directional but to a lesser degree (Table 17). Therefore appreciable noise reductions can be obtained at test sites simply by optimum orientation of the hammer drill exhaust with respect to exposed miners. This perhaps is an extreme example but the principle applied equally to industrial equipment and proper orientation sometimes proves worthwhile.

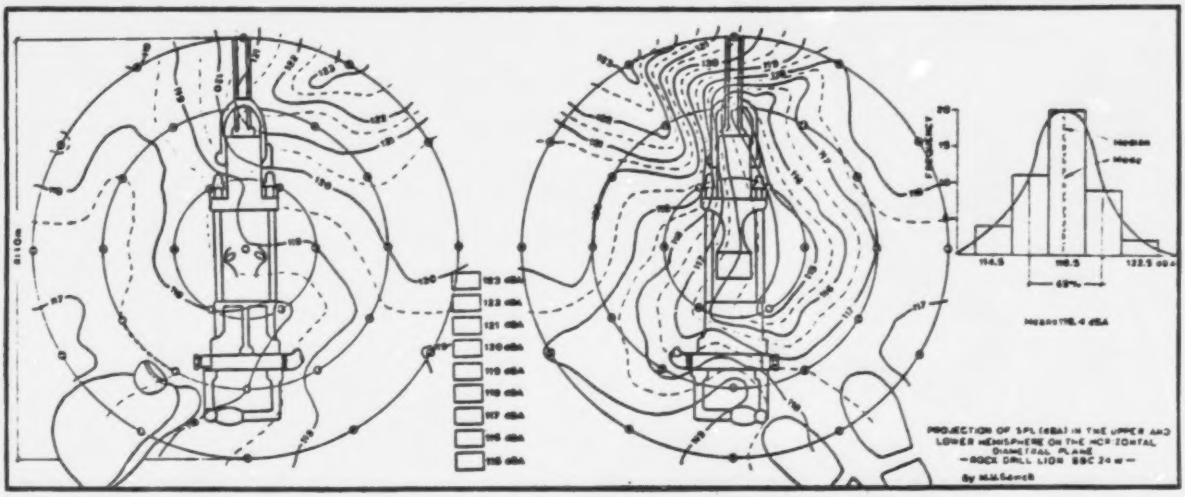
Compressed air is a common source of noise in the plant. When released into the plant environment from an open line, the high velocity air is capable of generating extremely high noise levels.

TABLE 17

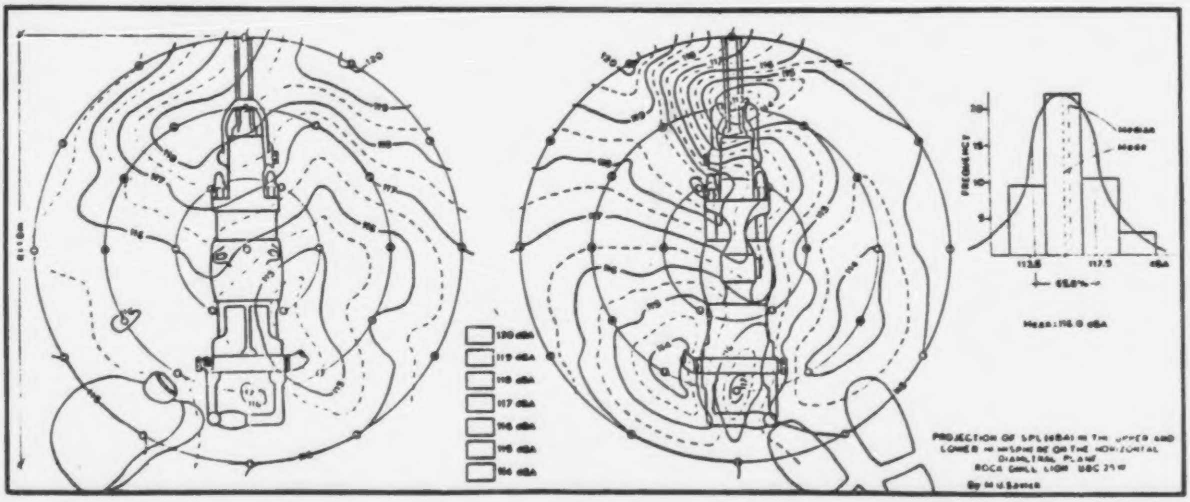
Projection of Izophote-SPL (dBA) in the Upper and Lower Hemisphere on the Horizontal Diametral Plane (70).


123 dBA
122 dBA
121 dBA
120 dBA
119 dBA
118 dBA
117 dBA
116 dBA
115 dBA
114 dBA
FREQUENCY
Median
Mode
114.5
118.5
122.5
dBA
68.9%
Mean=118.25 dBA

PROJECTION OF SPL (dBA) IN THE UPPER AND LOWER HEMISPHERE ON THE HORIZONTAL DIAMETRAL PLANE
- FEED LEG DRILL S63F -
By M.M.Savich


123 dBA
122 dBA
121 dBA
120 dBA
119 dBA
118 dBA
117 dBA
116 dBA
115 dBA
FREQUENCY
Median
Mode
114.5
118.5
122.5 dBA
68%
Mean=118.4 dBA

PROJECTION OF SPL (dBA) IN THE UPPER AND LOWER HEMISPHERE ON THE HORIZONTAL DIAMETRAL PLANE
— ROCK DRILL LION BBC 24 W —
By M.M.Savich


120 dBA
119 dBA
118 dBA
117 dBA
116 dBA
115 dBA
114 dBA
FREQUENCY
Median
Mode
113.5
117.5
dBA
65.0%
Mean: 116.0 dBA

PROJECTION OF SPL (dBA) IN THE UPPER AND LOWER HEMISPHERE ON THE HORIZONTAL DIAMETRAL PLANE
ROCK DRILL LION BBC 21 W
By M.M.Savich

Velocity can be reduced by spreading the total air flow over a larger area. This is the operating principle of the mufflers that are commonly seen on air cylinder and pneumatic tool exhausts.

Modification of the Sound Wave

Up to this point, the noise control procedures under discussion have involved the placement, substitution and modification of the noise sources. There are instances when there are not practical methods that can be used to quieten the source. In these instances, if one is to accomplish noise control, one must restrict one's attention to the emitted noise rather than the noise emitter.

A noise-containing structure may be anything from a small housing around a single noise source to a room or a building enclosing many sources. Regardless of its size, the principles involved are the same.

There are two important points to remember when considering the erection of a noise enclosure. First, if it is to be effective, an enclosure must have mass. The greater the noise reduction required, the greater must be the mass of the materials of construction. The second point to remember is that small leaks in the structure can severely reduce the noise reduction capabilities of an enclosure. The heavier the construction (i. e., the more noise reduction required), the greater the ability of noise leaks to limit the noise reduction capabilities.

A barrier provides a shadow effect and it performs best on high frequency noises. It seldom can be used to provide any worthwhile noise reduction on predominantly low frequency noises.

The best-known (though not necessarily the best) method of noise control is absorption within a room by the application of acoustical materials to walls and ceiling. It can be considered when the noise reduction required is not more than about 10 dB, when the noise is predominantly high frequency, when the room is reverberant and when reduction is not required close to the noise source.

Acoustical materials reduce only the noise that would otherwise be reflected from hard surfaces (e. g., walls, ceilings, floors, machinery, etc.) and returned to the room. It has no effect on the noise source or the sound waves radiating directly from the noise source.

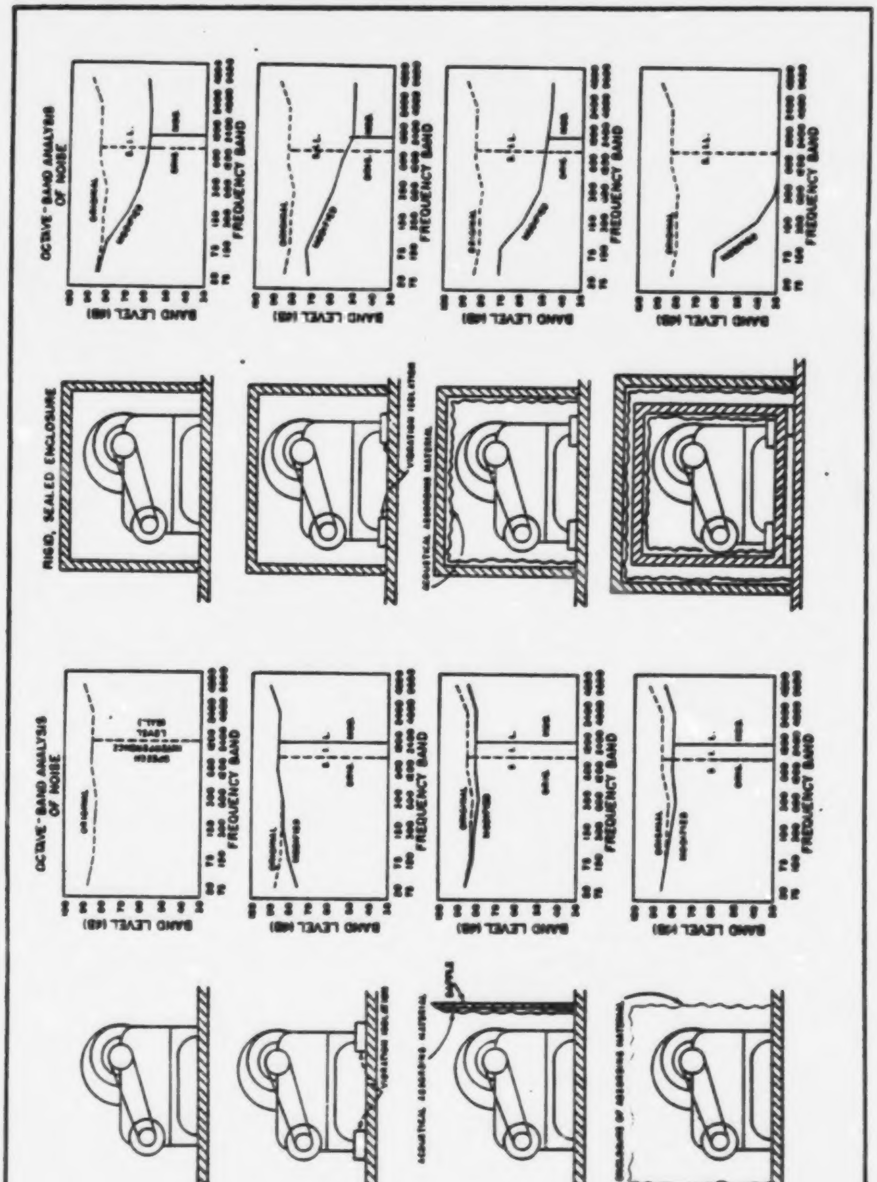

OCTAVE-BAND ANALYSIS OF NOISE
RIGID, SEALED ENCLOSURE
BAND LEVEL (dB)
FREQUENCY BAND
ORIGINAL
MODIFIED
S.I.L.
VIBRATION ISOLATORS
ACOUSTICAL ABSORBING MATERIAL
BAFFLE

Figure 28: Effects of Absorption, Transmission Loss, Damping and Vibration Isolation (General Radio Corporation).

Sound absorption is sometimes used to advantage in attenuating noise in ventilation systems. Lined ducts of various configurations and materials are commercially available. The attenuations they provide are predictable and are available from the manufacturer.

The final method of control to be mentioned is that involving the use of resonance phenomenon. One of the most common noise control devices using this principle is the automobile muffler and the hammer drill. The intent of the resonator in noise control is to reflect a portion of the noise energy back into the noise source.

The most unusual application of resonance phenomenon in noise control is for controlling relatively narrow bands of low frequency noise. They are especially useful as mufflers to control pulsating flow noises of restricted frequency range (e. g. , vehicle and vacuum pump exhausts). However, resonators can be designed to cover a wide frequency range.

8. 2 The Occurrence of Poor Noise Control in Canadian Mines.

Ingersoll Rand Canada Ltd. has published an 8-page catalogue of breakers with technical data (FORM 4335, 1971-2071). On seven pages, noise and vibration are discussed without any real technical data. The author has summarized the main information in Figure 29. From the sketch and figures we can conclude that the technical service made great efforts to offer the best possible data. The marketing service made the catalogue convinced that it would be best if the relative values for sound and vibration were included. But at Atlas Copco the technical service itself prepares the catalogues. The Atlas Copco data for the same types of breakers are in the Appendix.

If the data from Figure 29 are compared with the official data from the analysis of the Walsh-Healey Act (Table 18), the figure gets its real value.

The author has collected a great of noise level data from machines and engines and found that the data show wide variations in noise level. The Ingersoll Rand Catalogue refers to R. A. Baron' s "The Tyranny of Noise" (1970) Figure 29) but does not provide quantitative data.

Misunderstandings arise when processing measured noise data. A noise spectrogram is shown in Figure 30 (61). However, the diagram is inaccurate and suggests that the data has been analyzed incorrectly. Calculation indicates that the overall frequency (All Pass) should be 122. 5 dB and A-network should be 124 dBA.

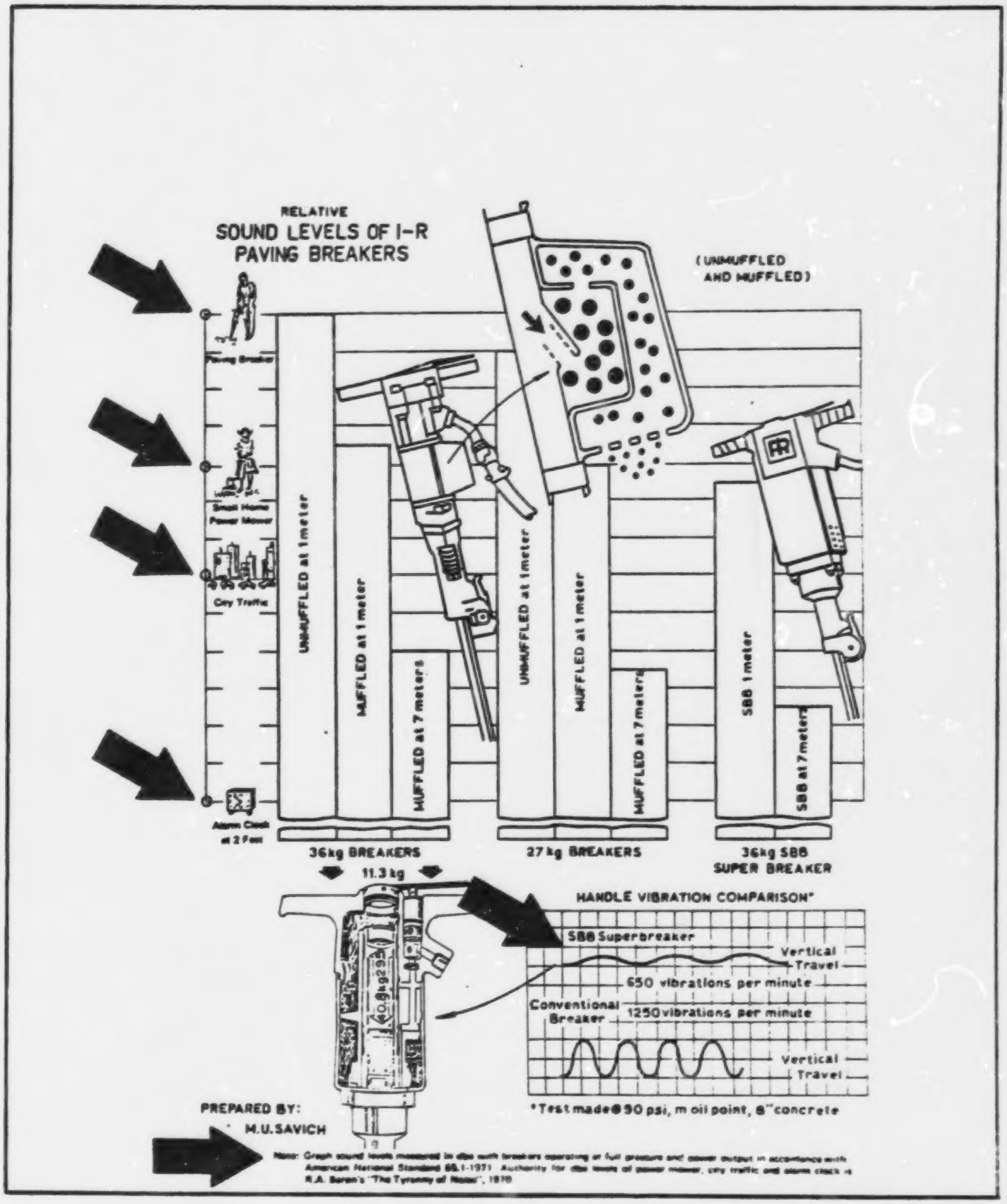


Figure 29: Relative Sound Levels of I-R Paving Breakers (Unmuffled and Muffled) and Handle Vibration Comparison.

TABLE 18

Typical Sound Levels Encountered in Daily Life and Industry *

Sound	Decibels (A scale)	Sound	Decibels (A scale)
Rustling Leaves	20	Air compressor	94
Room in a quiet dwelling at midnight	32	Air grinder	95
Soft whisper at five feet	34	Hammermill	96
Men's clothing department of large store	53	Plastic clipper	96
Window air-conditioner	55	Cut-off saw	97
Conversational speech	60	Home lawn mower	98
Self-service grocery store	60	Multiple spot welder	98
Household department of large store	62	Turbine condenser	98
Busy restaurant or canteen	65	150 cu ft air-compressor	100
Typing pool (nine typewriters in use)	65	Drive gear	103
Vacuum cleaner in private residence (at ten feet)	69	Banging of steel plate	104
Ringing alarm clock (at two feet)	80	High-pressure gas leak	106
Loudly reproduced orchestral music in large room	82	Magnetic drill press	106
Beginning of hearing damage - if prolonged	85	Air chisel	106
Printing press plant (medium size automatic)	86	Positive displacement blower	107
Heavy city traffic	92	Air hammer	107
Heavy diesel propelled vehicle (about 25 ft away)	92	Vacuum pump	108
Heavy duty grinder	93	Jet airliner (500-ft-overhead)	115
		Human pain threshold	120
		Jolt squeeze hammer	122

* From National Safety News "An Analysis... The Walsh-Healey and 90 dBA," April 1970, by Martin Hirschorn.

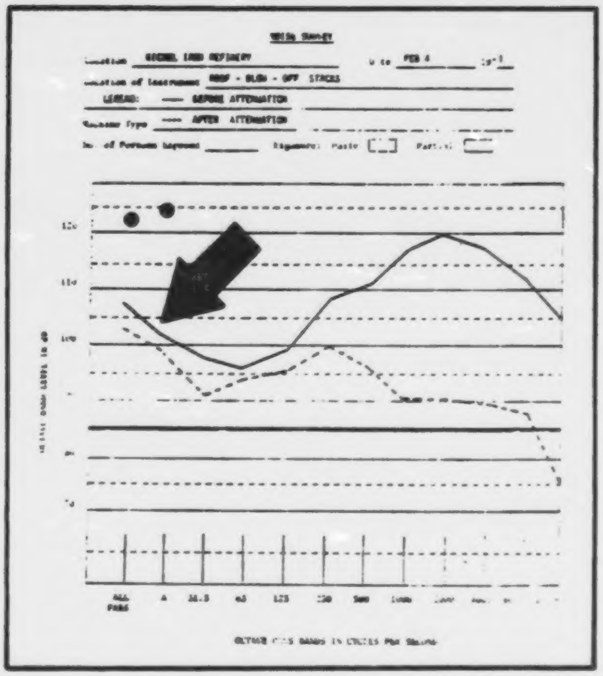


Figure 30: Noise Survey at Nickel-Iron Refinery before and after Installation of Mufflers on Blower Blow-Off Stacks.

In V. A. Pakalnis's diagram of noise spectra of airleg drills, standard and muffled drills, (66), we see two clearly separated lines. The difference of noise spectra between a standard drill and muffled drill at a frequency of 4000Hz is 4 dB and at 8000 Hz is 6 dB. At lower frequencies of 31. 5 Hz and 63 Hz the difference is about 5 dB.

The best constructed airleg drills could not achieve such a result, and this is the main problem in the fight for noise reduction (impact noise). For this reason we show the noise spectra data by Atlas Copco and Ingersoll Rand (Figure 32). The author has checked the Atlas-Copco data and found that the results are very close at 4000 Hz and 8000 Hz (Figure 33).

From the facts above we can conclude that V. A. Pakalnis's data are inaccurate.

The above three are very characteristic examples which confirm the fact that difficulties exist in the theoretical and practical points of view. In an effort to do a good job, very serious mistakes are made. This reflects a great need for a manual dealing with noise problems in mines.

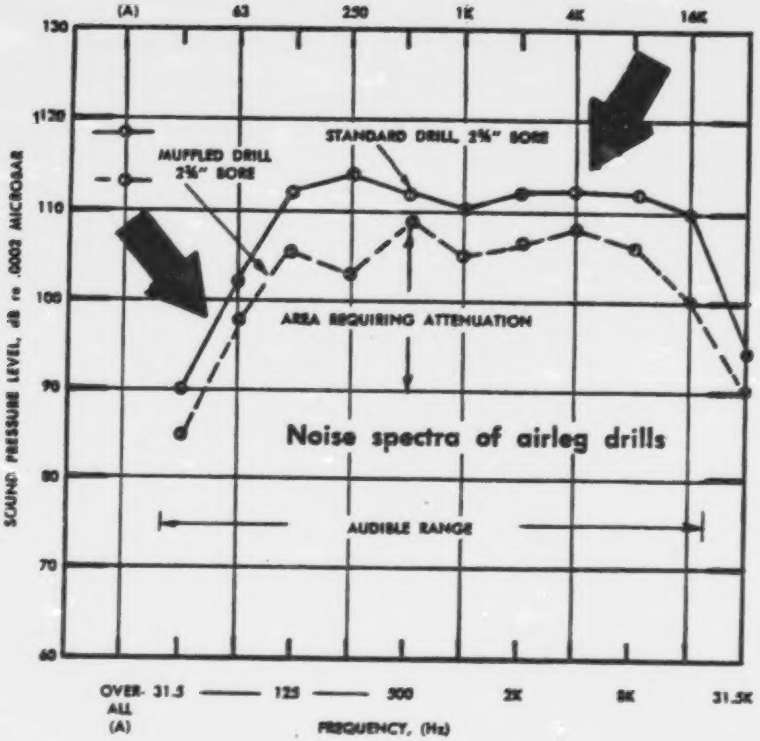


Figure 31: Noise Spectre of Airleg Drills (66).

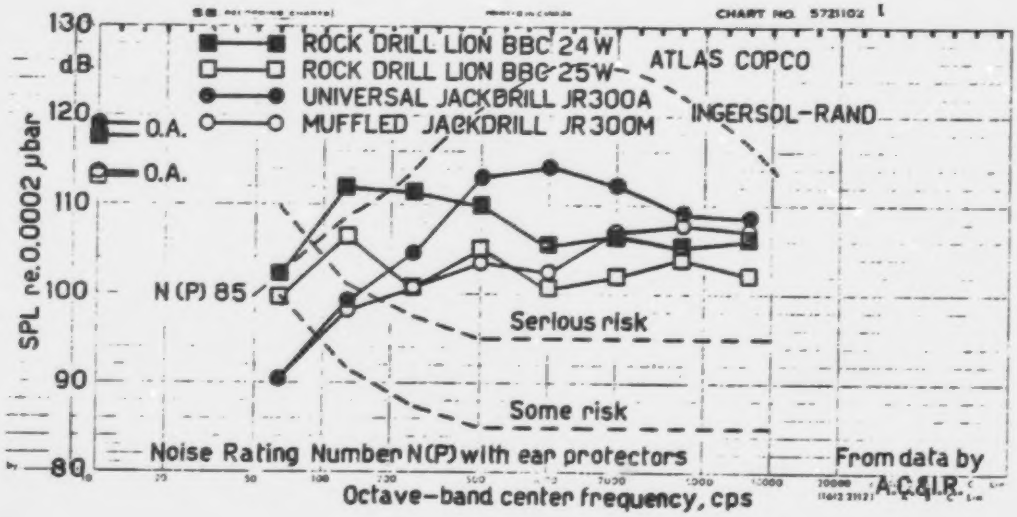


Figure 32: The Noise Spectra from Data by Atlas Copco and Ingersoll Rand for Drill Hammers of the Same Class.

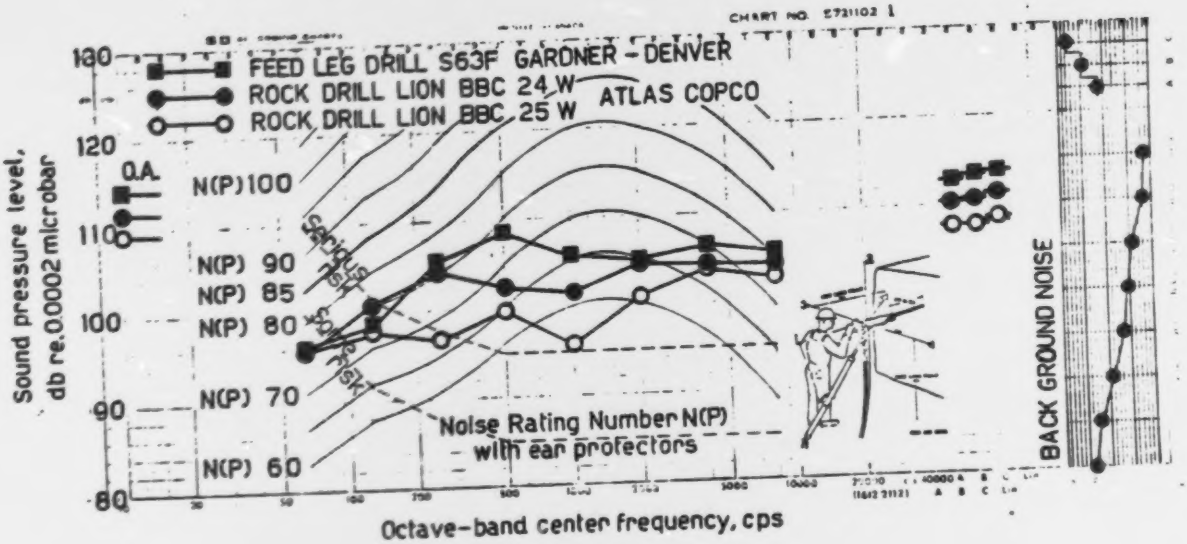


Figure 33: The Noise Spectrum Produced by the Drill Hammers (The CAGI Test Code).

8.3 Noise in Mining

In mining (surface and underground), noise should be divided into three sections:

1. Mechanical or impact noise, which is provoked by the vibration of hard bodies owing to impact friction or resulting from mechanical power (hammer drills, pneumatic machines, crushers, disintegrators, pumps, compressors, loaders, dredgers, etc.).

2. Aerodynamic and hydraulic noise, which is provoked by the movement of gases, vapours or liquids (ventilators, air pipe-lines, gas pipe-lines, vapour pipe-lines, aquaducts, hydraulic transport and machines connected with it, the noise due to moving gases, etc.).

3. Magnetic noise (electric motors, transformers, etc.).

8.3.1. Noise Generated by Hammer Drills

Rock drills may be classified into five categories (67, 68):

1. paving breakers or demolition tools;
2. jackhammers or demolition tools, jackdrills;
3. drifters;

4. stopers; and
5. downhole drills.

Paving breakers and demolition tools are hand-held tools designed to accomplish what their names imply. They range in weight from 7.0 to about 70.0 Rg, are solid steel, do not have automatic rotation, and are seldom used in mining. Jackhammers, drifters, stopers and downhole drills work on the same principle. In the hammer drill the reciprocating piston moves freely in the cylinder, striking blows on the end of the drill steel. Technical data are shown in Table 19 (69).

Noise is generally reduced either at its source, or at the listener's ear by changing the level from the source. The use of mufflers on small or medium hammer drills to isolate man from noise is just the beginning.

Silencers are usually divided into two categories - absorptive and reactive (70). In general all mufflers accomplish noise reduction by combining both effects to a certain extent, so that the distinction is arbitrary.

The absorptive silencers are used in cases where a narrow-band noise predominates, but the frequency varies because of a wide range of operating speeds.

The acoustic performance depends upon its dimensions, internal arrangement, and kind of absorptive material used. It is extremely important to correlate the acoustic performance with the flow rate through the muffler. The reactive silencer (muffler) is the simple expansion chamber, containing nothing at all but air (Figure 34).

Rock drill exhaust mufflers are generally a reactive type. A reactive muffler, usually composed of expansion chambers and resonators, attenuates a portion of the noise spectrum by reflecting noise out-of-phase back toward the body of the hammer drill. Absorptive materials convert sound energy by damping vibration and creating turbulence in the air flow (Silver 303, Holman).

In this report we will show the main types of mufflers and their advantages. Our task is not to become theoretically involved in the analysis of mufflers but to show their technical solutions.

TABLE 19

Classification of Rock Drills and Associated Tools				
Rock drill data	Light	Medium	Heavy	Down the hole
Netweight (kg)	21 - 30	30 - 50	> 50	from 12 - 218
Piston diameter (mm)	50 - 75	75 - 100	100 - 150	40 - 150
Length of stroke (mm)	20 - 70	35 - 70	~ 80	100 - 200
Bore (mm)	22 - 45	35 - 70	70 - 90	65 - 230
Drill Steel - ϕ (in.)	7/8" - 1"	7/8" - 1 1/2"	1 1/4" - 1 3/4"	Drill tubing
Drilling Speed (cm/min)	15 - 70	10 - 90	20 - 110	5 - 20
Maximum depth (m)	5	7 - 12	20 - 25	50 - 100
Air consumption at $6\ kg/cm^2 (m^3\ min)$	1.5 - 4.5	4.5 - 8	12 - 18	2.5 - 6
Noise Level (dBA)	104 - 118	106 - 126	~118	85 - 106
Noise reduction	muffled exhaust	muffled	control inside acoustical enclosure	----
Noise level reduction (dBA)	3 - 7	4 - 8	~ 24 - 27	----

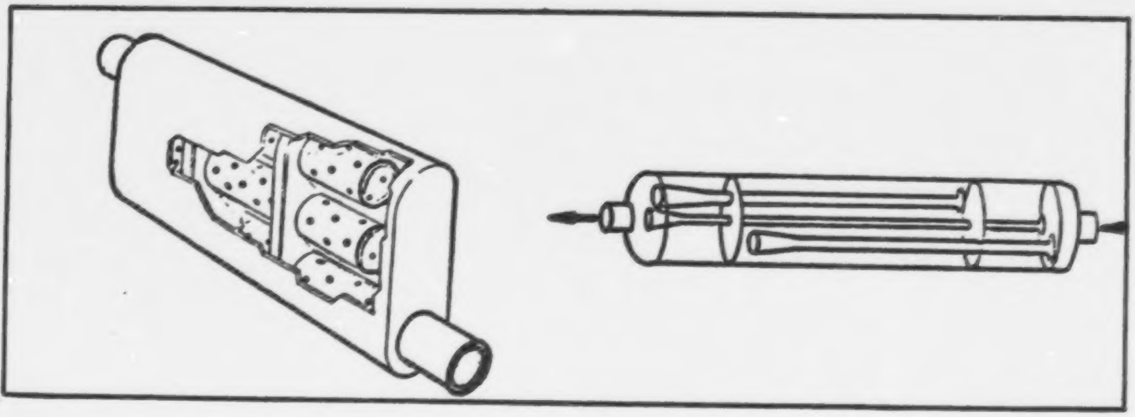


Figure 34 : Reactive Muffler.

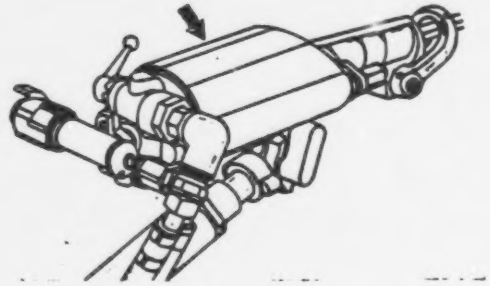
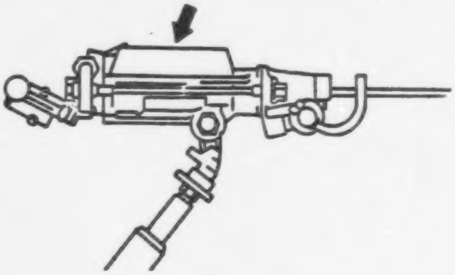
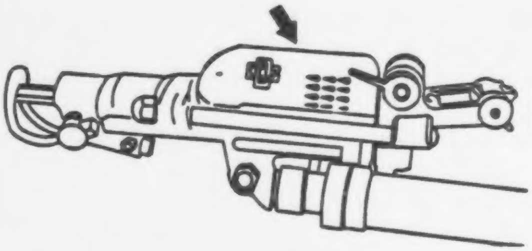
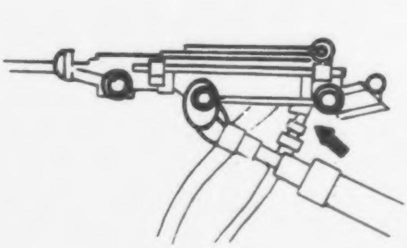
Even though many muffled hammer drills are on the market, there is no technical data about them. Atlas Copco provides some data but it is still insufficient to explain the details of construction and the reasons which led them to their design.

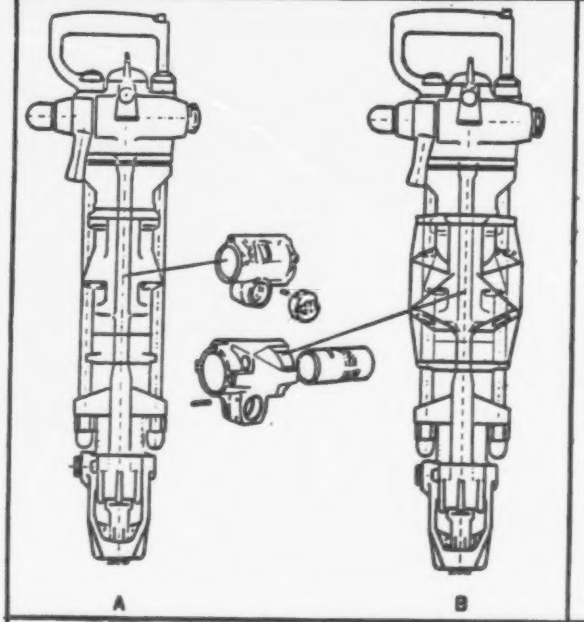
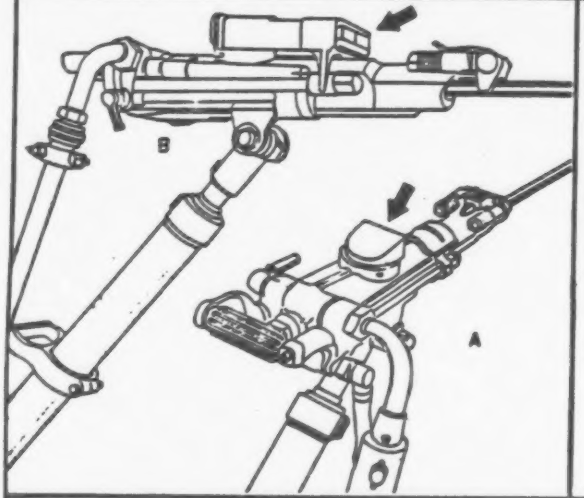
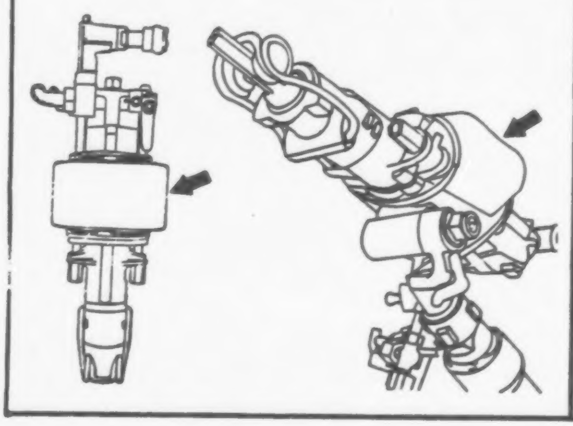
The hammer drills shown have different types of mufflers. Joy, Ingersoll-Rand and Gardner-Denver have similar technical solutions. A muffled type cylinder (reactive muffler) is situated on the upper side of the hammer drill. Zimco has a muffled cylinder on the lower side with the air exit on the front upper side. The patented silenced cylinder by Atlas Copco is based on the theory that exhaust air produces less noise when split up into many small jets. Toyo Rock Drills are equipped with a nose (directivity factor) and vibration-deadening devices. The directivity factor is determined by the position of the nose. On the more modern variety the nose is replaced by a built-in resonating chamber.

The Operator Cab (Figure 35) provides noise protection in heavy hammer drills. The sheet steel cab has two sliding doors, safety glass windows and a padded operator's seat.

A machine which partly replaces the hammer drill is the rock and concrete splitter. Pneumatic drilling and hydraulic splitting can easily be handled by one man. On production jobs, one man using the splitter can keep up with 3 to 5 drillers. It is easy to conclude that the splitter shortens the length of the man's exposure to noise.

The muffled light and medium hammer drills on the Canadian market are as follows: (71, 72, 73, 74, 75, 76, 77) :

	Type: The Joy AL-60 Air Leg Muffler: Reactive Unmuffled - Noise Level (dBA) 118 Muffled - Noise Level (dBA) 112.5
	Type: JR 300M Jackdrill Ingersoll-Rand Muffler: Reactive Unmuffled - Noise Level (dBC) 119 Muffled - Noise Level (dBC) 114
	Type: Feed Leg Muffled Drill (S63F) Gardner-Denver Muffler: Reactive Unmuffled - Noise Level (dBC) 118 Muffled - Noise Level (dB) no data
	Type: S-24M Air Leg, Zimco and U & N Machinery Company Muffler: Reactive Unmuffled - Noise Level (dB) no data Muffled - Noise Level (dB) no data

	Type: (A) Rock Drill Lion (BBC24W) (B) Rock Drill Lion (BBC25W) Atlas Copco Muffler: Reactive Unmuffled - Noise Level (dBC) 117 Muffled - Noise Level (dBC) 113
	Type: (A) Leg Drill TY 24-LD (B) Leg Drill TY 24 L Toyo Koygo Co. Ltd. Directivity factor: Nose Muffler: Reactive Unmuffled - Noise Level (dB) no data Muffled - Noise Level (dB) no data
	Type: Silver 303 Air Leg-Drill, Holman Muffler: Absorptive (durable synthetic material) Unmuffled - Noise Level (dBC) 119 Muffled - Noise Level (dB) 114

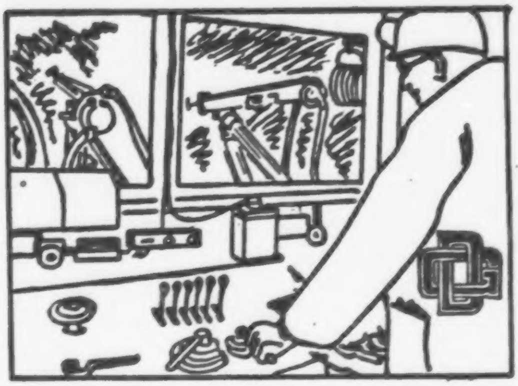


Figure 35: Operator Cab.

The methods of completely replacing the hammer drill are:

1) The cutting of rocks (carbonates) with a steel helicoidal rope and sand - without noise;
2) Cutting the canal machines - the noise level is 97 to 110 dBA.

There is no simple solution to the suppression of rock drill noise or to obtaining quantitative data on the noise intensity of hammer drills.

8.3.2. Noise Generated by Compressors

High-speed machines are noisier than low-speed units. For a particular design, sound will increase with speed anywhere from 20 log N_2/N_1 to 50 N_2/N_1, where N is revolutions per minute.

At low speeds, the sound of both compressors and pumps increases about 20 log N_2/N_1. High-speed compressor noise increases about 50 log N_2/N_1, while high-speed pump noise increases about 40 log N_2/N_1. This is because compressors run at a higher speed than pumps, and generate more noise.

The compressor noise problem is purely one of intake noise. The pulsing of air into the large slow-speed compressors had harmonics well into the audible range. For economic reasons, the mining companies, who had their own drilling and welding facilities, decided not to opt for a standard proprietary intake silencer, and a special reactive unit was designed and made. This consisted of a large cylinder divided into two expansion chamber resonators between which a side-branch resonator was formed in an annular cavity around a central perforated pipe, which is also extended, unperforated, halfway into the expansion chamber at each end.

The remaining problem of the propeller fans ventilating the compressor house was solved by fitting circular absorption silencers, lined with 5 cm thick mineral wool, and with a cylindrical sound-absorbent pad in the centre. A small drop in air volume resulted because of the resistance of airflow imposed by the silencers.

In the mining plant, engineers were about to fit another silencer at the base of the exhaust stack, although the problem was being caused elsewhere. Sound absorption is often attempted in compressors, but it is useless at such low frequencies unless an absorptive splitter silencer of vast dimensions can be constructed. As there is almost no middle- and high- frequency noise at the intakes to these compressors, that sort of splitter silencer would be a great waste. In these cases, wrong diagnoses would result in large needless expenditures.

All medium compressors (125 to 335 cfm) have a degree of silencing built into them. Even the standard unit has a venturi noise suppressor in the air-intake system, and in many cases, this is quite sufficient to cover normal conditions.

Certain countries have laid down rules for noise suppression in city centres, in the vicinity of hospitals, etc., and special equipment is required by contractors working in such areas.

Atlas Copco can offer further stages of noise suppression for medium compressors. For particularly strict noise conditions, special units are available with Deutz diesel air-cooled engines, whose noise level is reduced to only 70 decibels and which can be compared with that of a normal automobile. Medium silenced compressors have the same features as standard units.

The two compressor stages are enclosed in separate housings (Figure 36). The set, completely equipped with cooler, drive, regulating and safety devices, is mounted on a base frame and delivered ready to run. The gearbox and motor are rubber-mounted on a base frame.

The maximum capacity is 56.6 m^3/min (2,000 cfm) at 7kg/cm^2 (100 psi) pressure (Atlas Copco and Ingersoll-Rand).

Packaged air compressors (180 to 265 cfm) are completely self-contained compressed air systems which deliver clean, cool air at rated capacity and pressure at the discharge of the package. The heavy metal enclosure is acoustically lined for low noise level (a type of high-frequency silencer) (Figure 37).

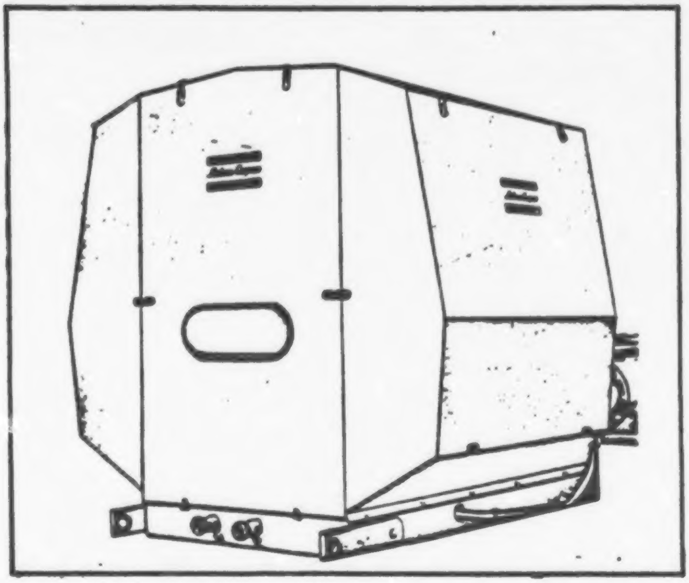


Figure 36 : Compressor Set Enclosed in a Noise-Suppressing Canopy.

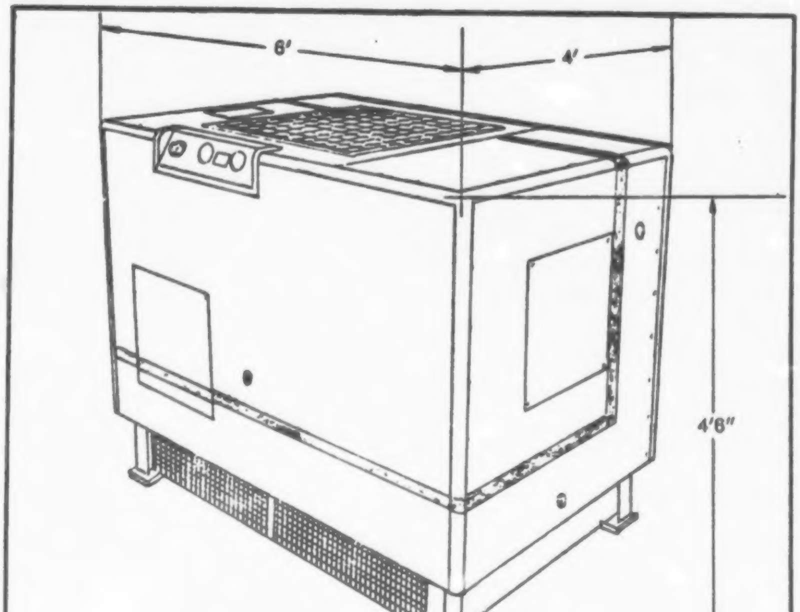


Figure 37 : Packaged Compressor.

It is important in the vibration isolation of a compressor that there be no rigged mechanical ties between the machine and the building structure which would reduce the effectiveness of the mounting system.

Figure 38 illustrates a noise problem in which a vibration-isolated compressor was generating vibrations in the floor overhead because the compressor piping was originally mounted rigidly to the overhead floor slab. The following steps were taken to reduce the floor vibrations:

1. In the pipeline, two flexible couplings were inserted, oriented 90° to each other.
2. A 150 lb. mass was attached to the pipe beyond the second flexible coupling in order to increase the inertia of the pipe.
3. The mass and the pipe were supported from the floor slab by means of vibration-isolation ceiling hangers.

On the large crushers, mills, pressers, etc., vibration isolation is done by built-in vibration mounts. The protection from noise is done by:

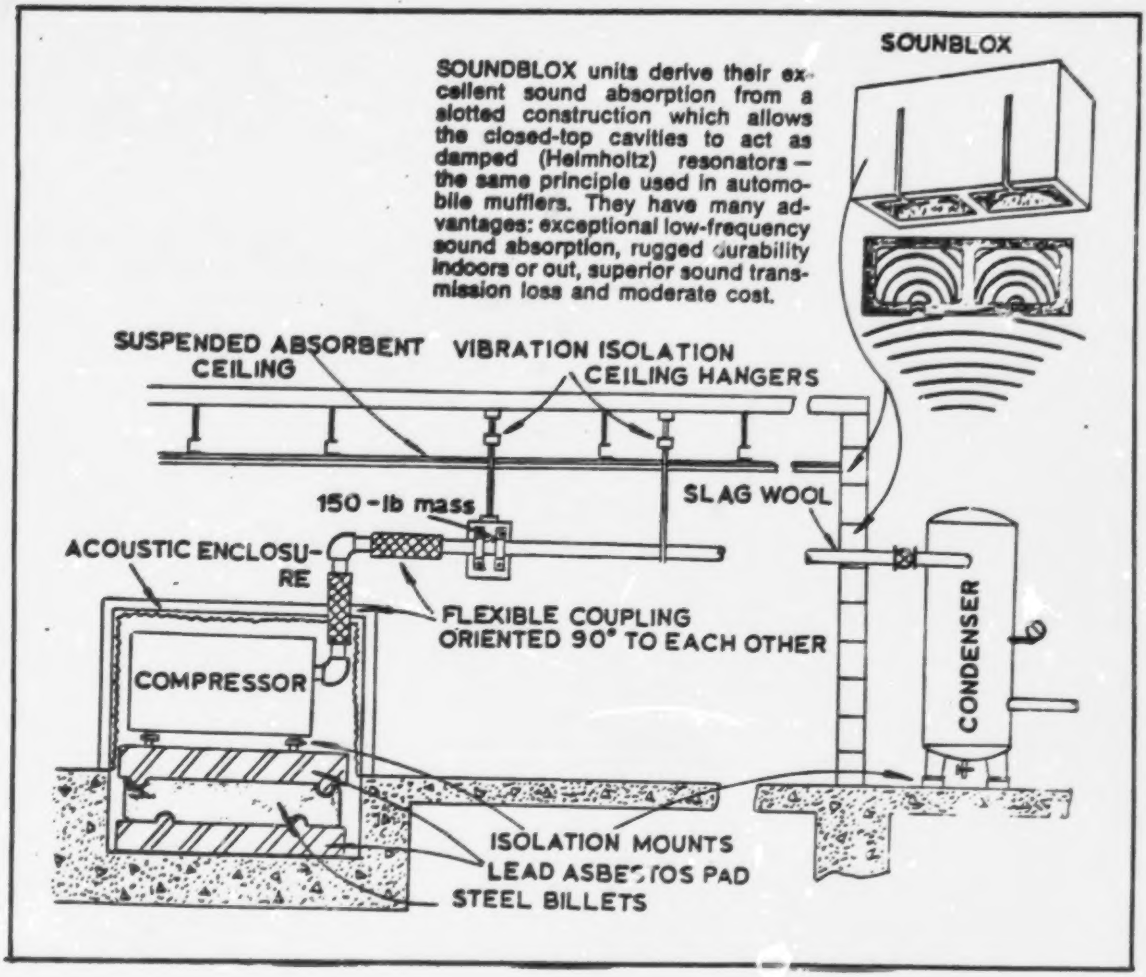
- an acoustically absorbent partial enclosure,
- an acoustic enclosure,
- functional sound absorbers which can be located close to noise sources,
- partial height barriers,
- vibration-isolation from girders and ceiling which has sound-absorbent glass-fiber baffles,
- an acoustical wall.

Air winches meet a great demand within modern industry, in mines and quarries, on board ships, within contracting, etc. There are three or four basic types in more than 30 different versions with capacities ranging from 300 to 2000 kg.

Air winches are the ideal equipment for jobs in a moist, acid or salty atmosphere or where there is risk that explosive gases will accummulate; they are even often the only choice.

The winches are designed to satify the most stringent mine and industrial safety codes. Air winches now have efficient noise-absorbing expansion pockets for the exhaust air (Figure 39).

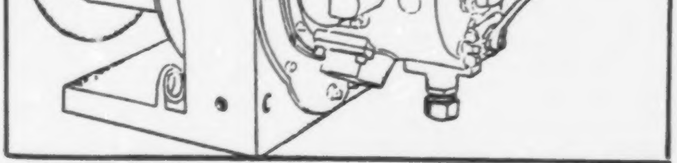
The mine shovel-loader can be used when driving tunnels varying in width from 1. 8 to 2. 5 m (6 to 8 ft 3in.) and having a minimum height of 2. 2. m (7ft 3 in.). Its simple and compact design is based on extensive experience in the manufacture and application of loaders.



SOUNDBLOX units derive their excellent sound absorption from a slotted construction which allows the closed-top cavities to act as damped (Helmholtz) resonators — the same principle used in automobile mufflers. They have many advantages: exceptional low-frequency sound absorption, rugged durability indoors or out, superior sound transmission loss and moderate cost.

SOUNBLOX
SUSPENDED ABSORBENT CEILING
VIBRATION ISOLATION CEILING HANGERS
150-lb mass
SLAG WOOL
ACOUSTIC ENCLOSURE
FLEXIBLE COUPLING ORIENTED 90° TO EACH OTHER
COMPRESSOR
CONDENSER
ISOLATION MOUNTS
LEAD ASBESTOS PAD
STEEL BILLETS

Figure 38: Vibration-Isolation Mounting of the Piping Connected to a Compressor.



Efficient noise-absorbing expansion pocket for the exhaust air.

Figure 39: Air Winch Equipped with Automatic Two-Shoe Holding Brake.

Flexible, trackless shovel loader systems are built for heavy-duty work in hard-abrasive rock. (Different combination: an auto-loader... a combination of shovel loader and dumper car). Even under severe conditions they reach a production rate which cannot economically be matched by any other method of mucking.

All types of loaders are remarkably silent-running and very easily operated, thus reducing operator fatigue. Each motor is fitted with a separate absorption silencer enclosed in the gear box. The exhaust air from the controls is responsible for a large proportion of the operating noise. On the different combination of loaders, the air controls are provided with special silencers keeping the noise at a low level (Figure 40).

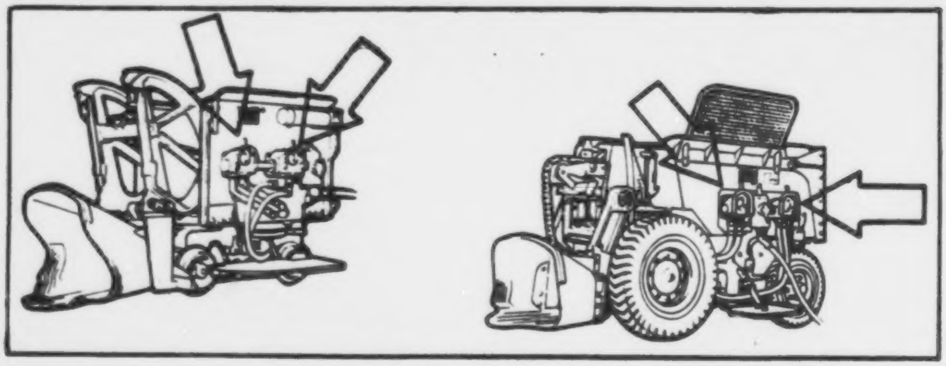


Figure 40: Special Silencers and New Controls to Reduce Operator Fatigue.

The machines can now be equipped for remote control operation, an advantage in confined stopes exposed to rock falls, and a benefit generally to the operator who can work the machine without having to ride it (Figure 41) (78).

He is not exposed to vibrations. When he stands 6 meters away the noise level is 8 to 9 dB(A) lower. Remote control allows safer and easier loading, lower dust concentrations, more-easily-trained personnel, and mining of ore not previously accessible because of cave-in-danger.

"A revolutionary breakthrough in minerals processing", was described and introduced at the American Mining Congress convention on September 18, 1972 (79).

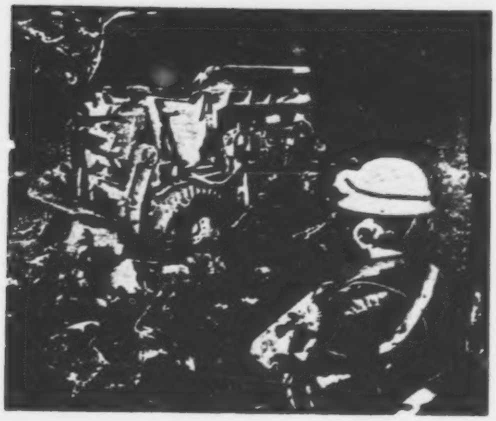


Figure 41: The Remote Control Operation.

The basic principle of the process is to take advantage of the fact that ores and other solid substances are weaker in tension than in compression, and to cause them to fracture through tension at their integral grain boundaries. The material to be processed is loaded into a chamber, and a compressible working fluid is introduced under medium pressure.

A fast-opening (less than 15 milliseconds) discharge valve is then opened, and the working fluid begins to expand, causing the material to become workable.

A cost comparison was carried out on the complete grinding section of a 25,000 ton-per-day porphyry copper operation to crush and grind 2 in. feed to 97% passing 48-mesh. In this comparison, on an installed basis, the process equipment replaced both the tertiary crushing and ball mill circuits. Capital and operating cost savings were approximately 33%.

The advantages of the new system are: low price and elimination of dust and noise. The small dimension equipment and its installation underground does not represent any problem. It is possible that the real solution lies in both mill installation and waste disposal underground.

8.4 Rubber Linings

Rubber linings have been used for many years to protect equipment against abrasion and corrosion. The qualities of rubber as a noise abator are receiving attention now as a result of the Walsh-Healey Act, National Health and Safety Act, and local and state laws and regulations on noise levels.

Today, as cost is one of the main factors in production, producers are very interested in reducing costs of wear linings and plates. These costs can be reduced principally by:

- finding new materials or new designs,
- finding cheaper lining materials,
- improving lining procedures.

Wear can be divided into two classes:

1) mechanical wear, and
2) chemical wear or corrosion.

Mechanical wear is caused by impact and abrasion. Wear by corrosion is too often overlooked in unit processes such as grinding, pumping and classifying (wet materials).

The factors which affect wear can be divided into two broad classes:

1) the physical and mechanical properties of the material, and
2) the movement of the material.

The most important factors for the choice of rubber are:

1) the size and shape of the material,
2) the angle of impact and velocity of the material, and
3) the damping effect of the rubber or type of abrasion:
    a) slurry
    b) sliding,
    c) impact or tumbling,
    d) impact-cutting and gouging.

With the above data, the proper type and gauge of rubber lining can be selected. Rubber linings are not a cure-all for every abrasion and noise problem (Figure 42). At incline angles of 5 to 30 degrees steel resists impact abrasion better than rubber.

To make it easier to discuss, let us divide different applications of rubber lining to abate noise and abrasion into five main groups:

1. devices for pulp handling,
2. grinding mills,
3. screens and trommels,
4. other ore-handling equipment, and
5. other applications of interest.

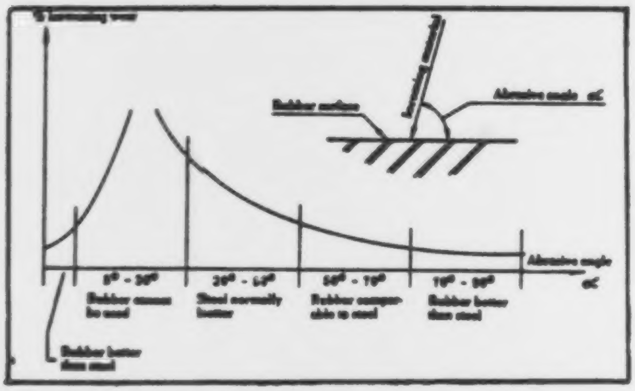


Figure 42: Comparison of Impact Abrasion Wear - Rubber versus Steel.

Devices for Pulp Handling

The most common use in the mineral dressing industry is a lining for pumps, tuber and cyclones.

Grinding Mills

The lining in a mill has two main functions:

a) to protect the shell and heads from wear
b) to transmit the grinding energy to the tumbling load.

The rubber mill linings (Figure 43) are produced to fit different types of mill designs. The range of lining products is based on long experience of heavy-duty rubber and on development work being carried out in collaboration with the mining industry.

The mill linings are composed of heavy-duty rubber units for the shell, the inlet and discharge heads, and discharge grates.

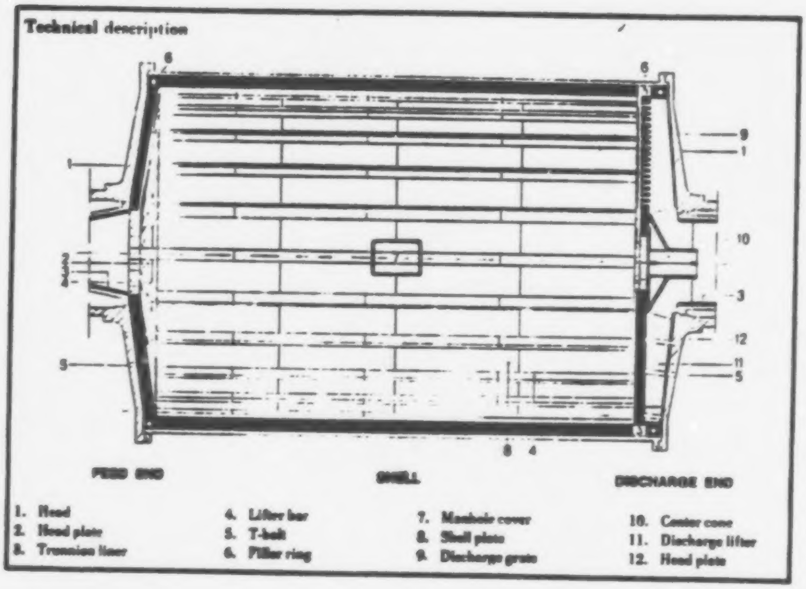

Technical description
6
6
9
1
1
10
3
12
5
11
5
8
4
FEED END
SHELL
DISCHARGE END
1. Head
2. Head plate
3. Trunnion liner
4. Lifter bar
5. T-bolt
6. Filler ring
7. Manhole cover
8. Shell plate
9. Discharge grate
10. Center cone
11. Discharge lifter
12. Head plate

Figure 43: Cross-Section of a Mill.

Comprehensive tests run in different types of mills have proven that heavy-duty rubber under certain conditions is clearly superior to steel as lining material. Completed installations and test reports demonstrate that rubber mill linings reduce grinding costs. Liner life lengthens. Replacements are required at longer intervals and take less time. The weight of the liner is reduced by up to 85%.

The rubber mill linings furthermore provide excellent sound insulation, reducing the noise level by as much as 4. 5 dB. In the steel balls ϕ 1 1/4" the reduction in noise is not felt. Examinations and measurements in the future must show the true parameters: grinding costs, efficiency, ϕ steel balls, noise. Now there are different opinions about these parameters.

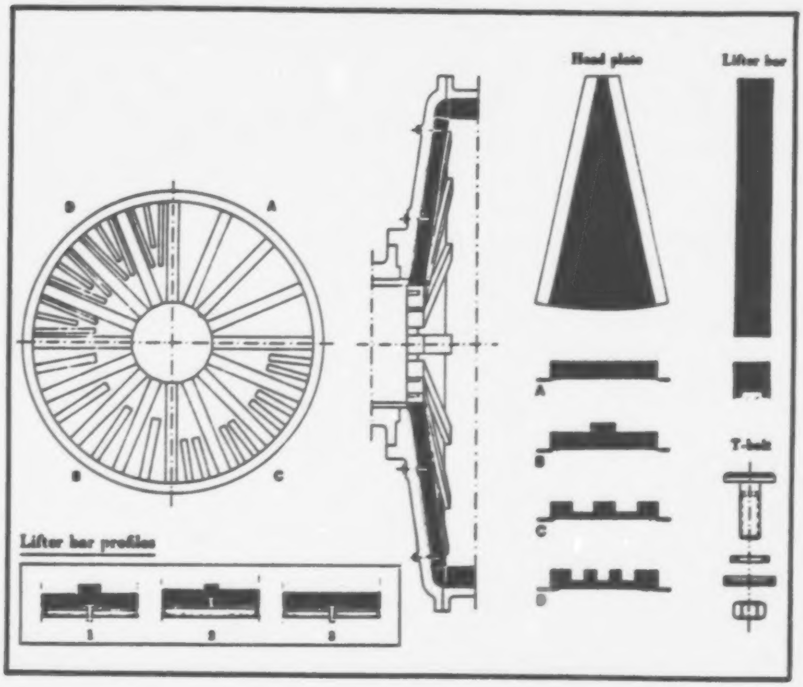

Head plate
Lifter bar
D
A
B
C
A
B
C
D
T-bolt
Lifter bar profiles
1
2
3

Figure 44: Alternative Rubber Profiles for Feed Heads.

1. The most common lifter bar profile. Bar height varies between 2 and 4 in.

2. An extra detachable lifter bar to prevent the material from sliding along the rubber in the case of acute angles of incidence in mills where wear is heavy and spacings wide.

3. Smooth head lining. Used chiefly in rod mills or ball mills, running at high or super critical speeds.

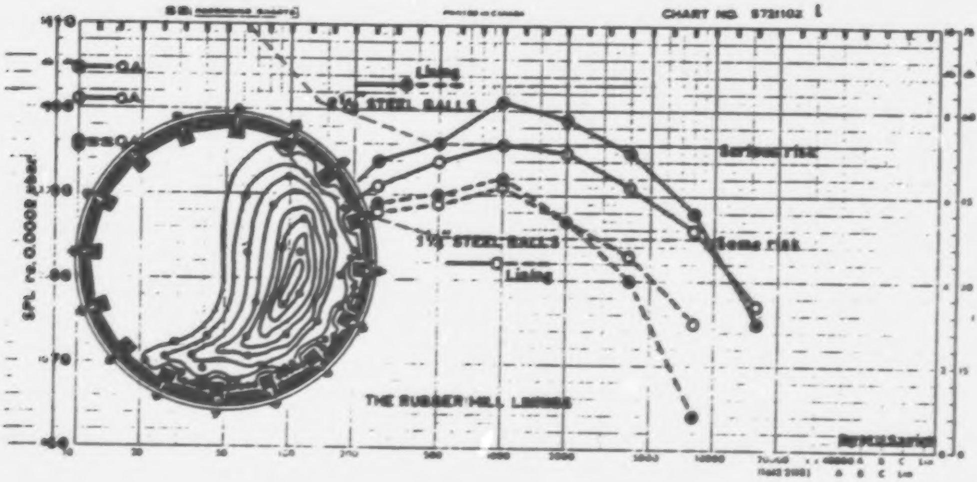


Figure 45 : The Rubber Mill Linings Reducing the Noise Level.

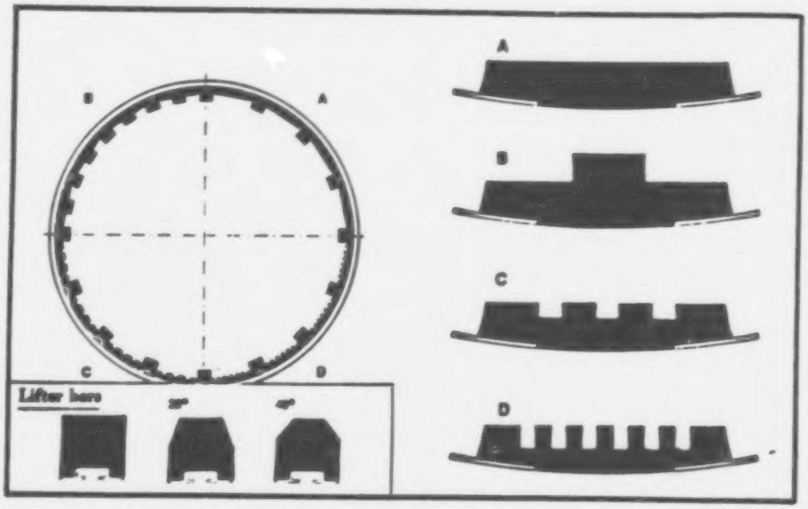


Figure 46 : Alternative Rubber Profiles of Shell Linings.
The lifter bars are supplied as standard in one of the above profile variations as determined on the basis of mill operating data.

Most of the mines in Canada, and in the world, do not use the lining in grinding mills. The lining in a rod mill has been used successfully in a cement raw mill, where wet grinding is used. From a working safety point of view, the light weight of the rubber and its noise reducing characteristics have been greatly appreciated. A Swedish cement plant discovered that the noise level in a rubber-lined mill is 10 decibels (85%) lower than in a steel-lined mill (80).

This decrease is important as even rather short exposure to loud noise can cause permanent hearing injuries (Figure 47).

Rubber was first applied to screen decks purely as abrasion protection. It was soon found that rubber not only served this purpose very well, but also considerably reduced choking if the holes in the rubber were made smaller than the holes in the metal deck.

This discovery led to more flexible rubbers. Developments in Sweden have ranged from rubber-on-steel, fabric and rubber, and cord reinforced rubber, to the contemporary types based solely on rubber in special doubled designs.

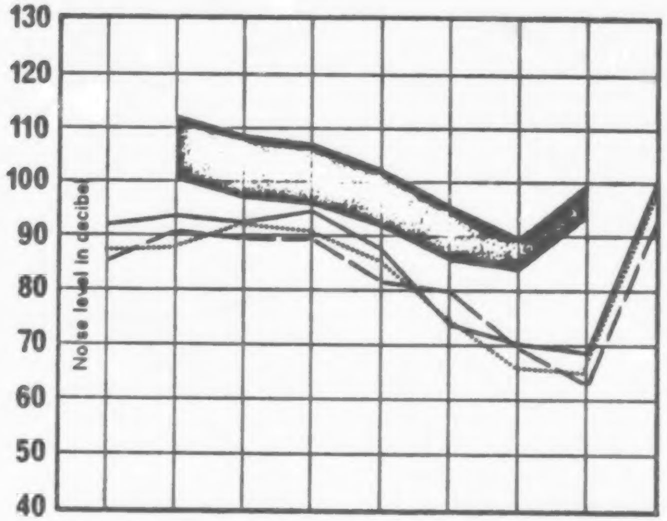
The all-rubber screen offers higher capacity and improved economy in screening material from 1mm to 200mm (1/32 to 8 in.). No general rule can be given as regards the extra life enjoyed by rubber screens compared with steel types, but the following examples give some guidance, compared with steel screens:

for iron ore	22 times,
for macadam	17 times
for pellets	9 times
for coke	7 times.

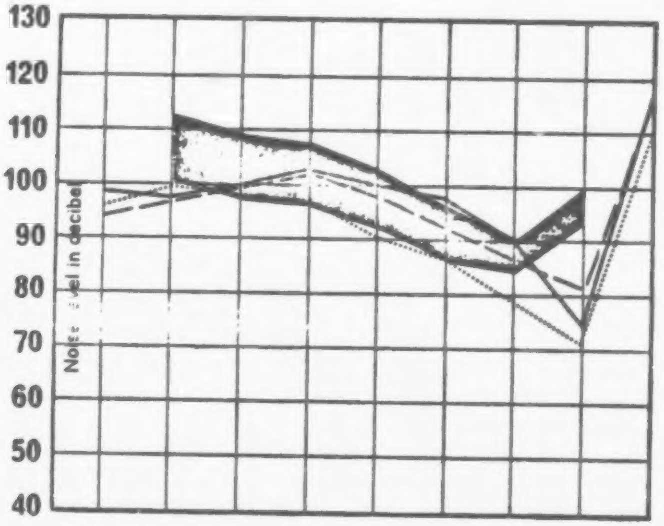
Furthermore, rubber screens contribute to good working conditions through the effective reduction of the noise level (Figure 48).

Five factors determine the choice of rubber wear:

1. Fastening methods,
2. Material handled,
3. Height of drop,
4. Angle of impact,
5. Ambient conditions.



Rubber liner: ★ — — — = feed end; ★ ——— = middle of mill; ★ ····· = discharge end; ▇ = limit zone, above which there are great risks of auditory injuries.



Steel liner: ★ ····· = feed end; ★ ——— = middle of mill; ★ — — — = discharge end; ▇ = limit zone, above which there are great risks of auditory injuries.

Figure 47: The Noise Level in a Rubber-Lined and Steel-Lined Mill in the Swedish Cement Industry (80).

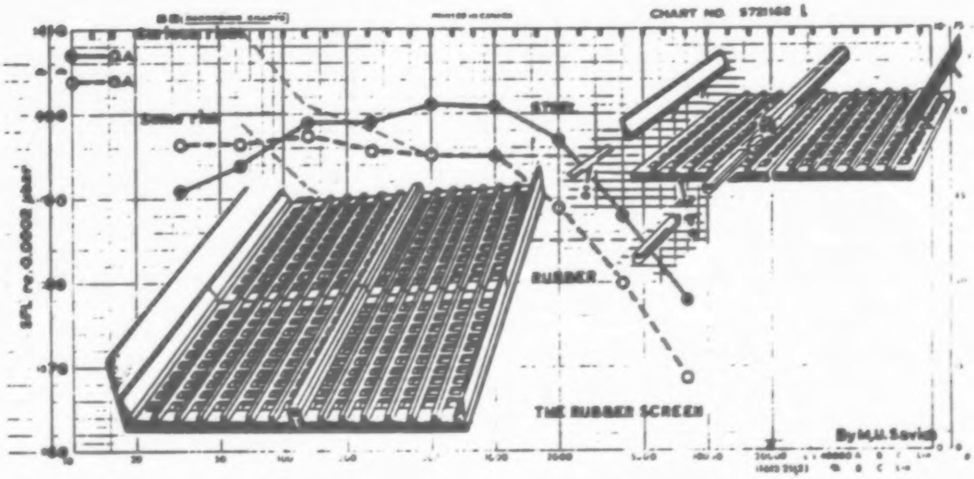


Figure 48: The Rubber Screens Contribute to Reduction of the Noise Level.

Each of these five factors influences the increase or decrease of noise. Detailed measurements and studies were not done but should be done . In order to decrease noise to a satisfactory level, the possibility exists that the milling process would be done underground; this is economical because transportation costs would decrease and the taillings could be used as backfill. However, if classified taillings are to be used for backfill underground, one should ensure maximum recovery of metal from the flotation process. Several European countries have started secondary processing of taillings because the market price of those metals which were not exploited in the beginning is now high. This shows how technology and the environment are closely related.

It should be noted that backfilling underground contributes to the cleansing of water and thus solves one of the main problems that exists today: water pollution.

Trommel screens are used either as a separate screening unit for classification purposes or as scrap screens in connection with grinding mill discharge. The noise levels are 100 to 105 dBA.

Other Ore-Handling Equipment

In launders and chutes it is possible to fully utilize the flexibility of rubber (Figure 49). It may be supposed by a steel backing; however, from the point of view of wear, it should be free-hanging.

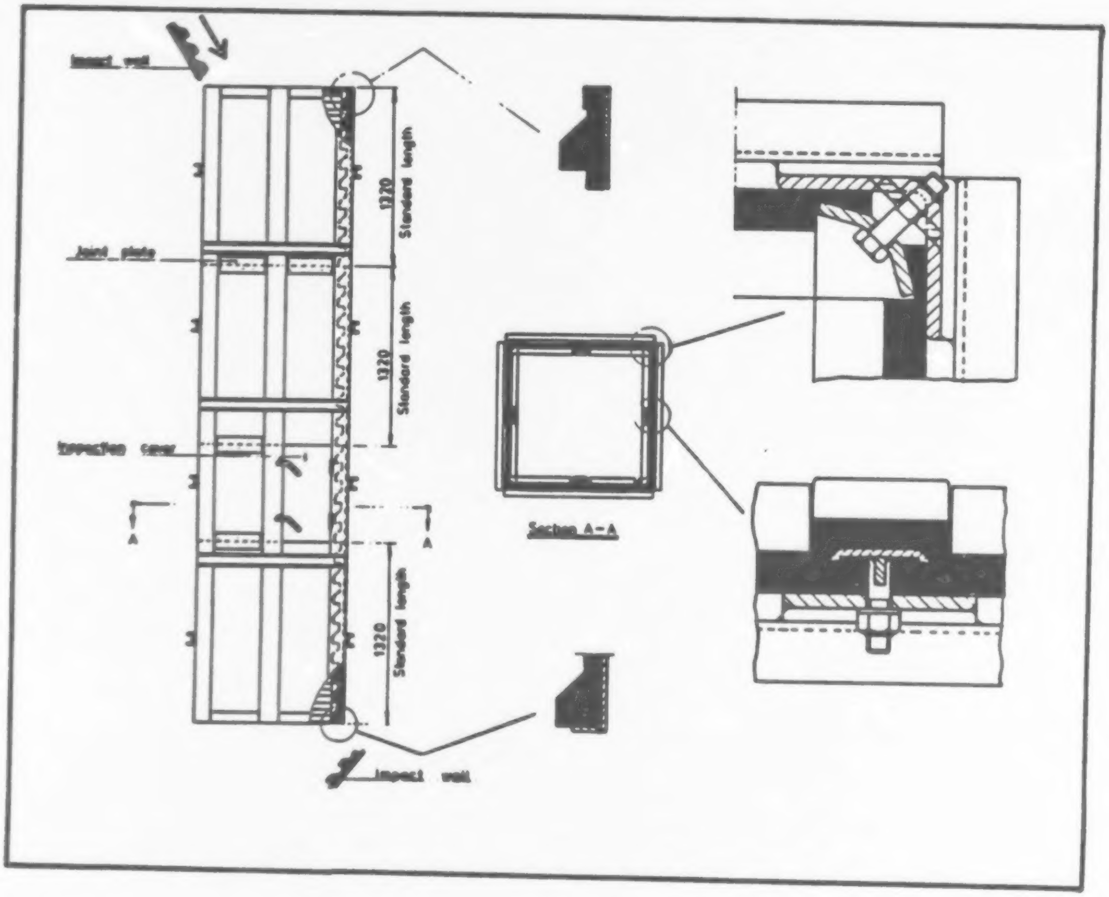

Impact wall
Joint plate
Inspection cover
1320 Standard length
1320 Standard length
1320 Standard length
A
A
Section A-A
Impact wall

Figure 49: Wear Components Rubber Chute.

Rubber bottom lining was installed in the 20-ton Jeto-skips of the LKAB unit at Malmberget, Sweden, in September, 1961 (Figure 50). The plate weighs approximately 1150 lbs and has a length of 88 in., a width of 55 in., and a thickness of 6 in. Individual ore lumps may weigh as much as 1100 lbs and the direct vertical drop may be approximately 23 ft. The skip is filled in 12 sec, which represents a charging rate of 1.7 tons/ sec.

The impact deflector (Figure 50 - B, C) has been used in a trans-shipment station. When the element had worn down after about 2 years of use, it had handled no less than 4,002,013 tons of iron ore. The earlier manganese steel deflector stood up only to about 500,000 tons.

As mentionned previously, rubber effectively decreases the noise level. Any steps taken to improve the working conditions, should include reduction of risk of permanent or temporary auditory injury.

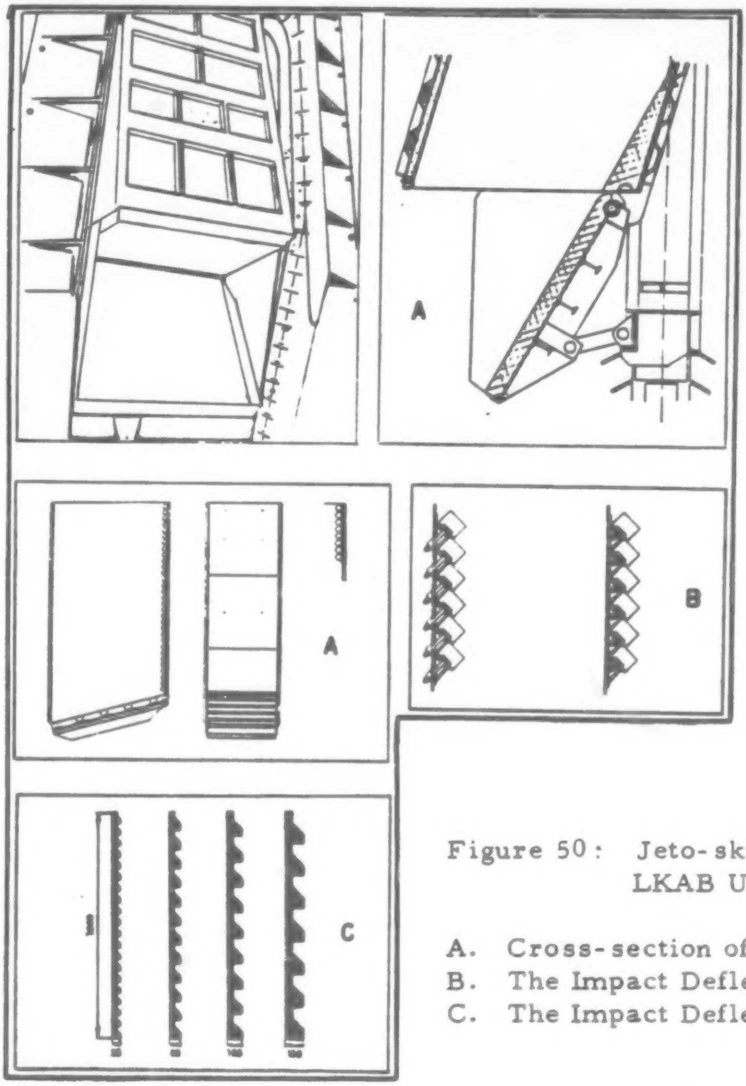


Figure 50: Jeto-skips of the LKAB Unit:

A. Cross-section of Skip.
B. The Impact Deflector.
C. The Impact Deflector.

Figure 51 shows the difference in noise level between steel and rubber at the skip of the LKAB, Sweden (81).

Following Swedish experience, the American and Canadian producers of rubber products have made a great progress in the past two years.

The Good Year Tire and Rubber Company of Canada Limited, introduced Armabond and Armaplate rubber linings.

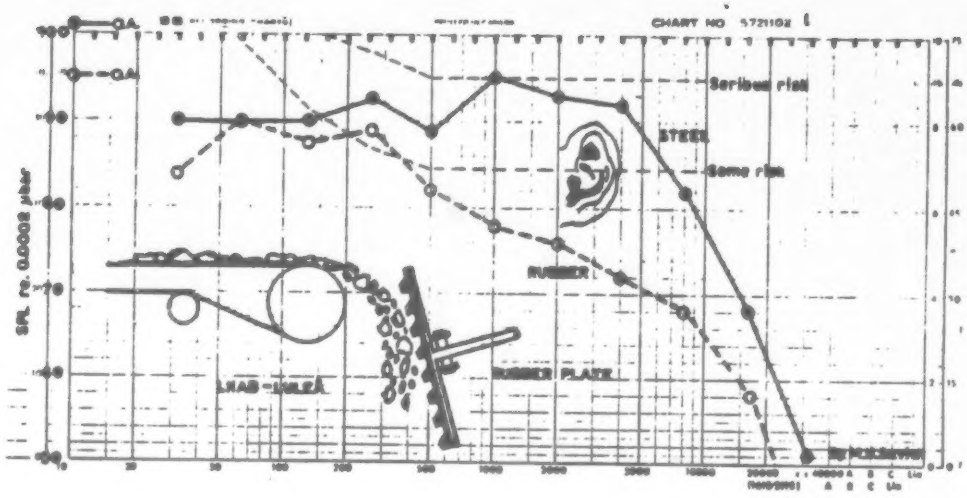


Figure 51: The Impact Deflector to Reduce the Noise Level.

The effectiveness of these linings in reducing the noise level of bare steel plate is shown in Figure 52. Their effectiveness at different frequencies is shown in Figures 53 through 56. The test procedures used to assemble the data was: "Test Setup for Noise Abatement Measurements".

Reduction of noise by rubberbacked steel plate (Armaplate) is greater when the impact is on the steel side.

The size and shape of the rocks, the method of loading and height of drop are factors that will influence the wear of truck bodies and chasses.

The dampening effect of a rubber lining will prevent stresses and deformation as the impact is absorbed by the rubber plates. During loading, the rocks will hit the rubber at the most favourable angle, (90°) and very little wear will occur (Figure 57).

Handily-positioned controls and instruments, along with exceptional visibility from the cab constribute greatly to remarkable ease of operation. Acoustical and thermal cab insulation and adjustable seating and steering provide maximum comfort. All result in increased operator effieciency. Noise level in the cab is 87 dBA to 92 dBA.

During the loading a high level of impact noise is reached. High frequencies reflect off a target, but transmission through metal must be very high. If motor noise is added to this, it will possibly exceed the permissible level.

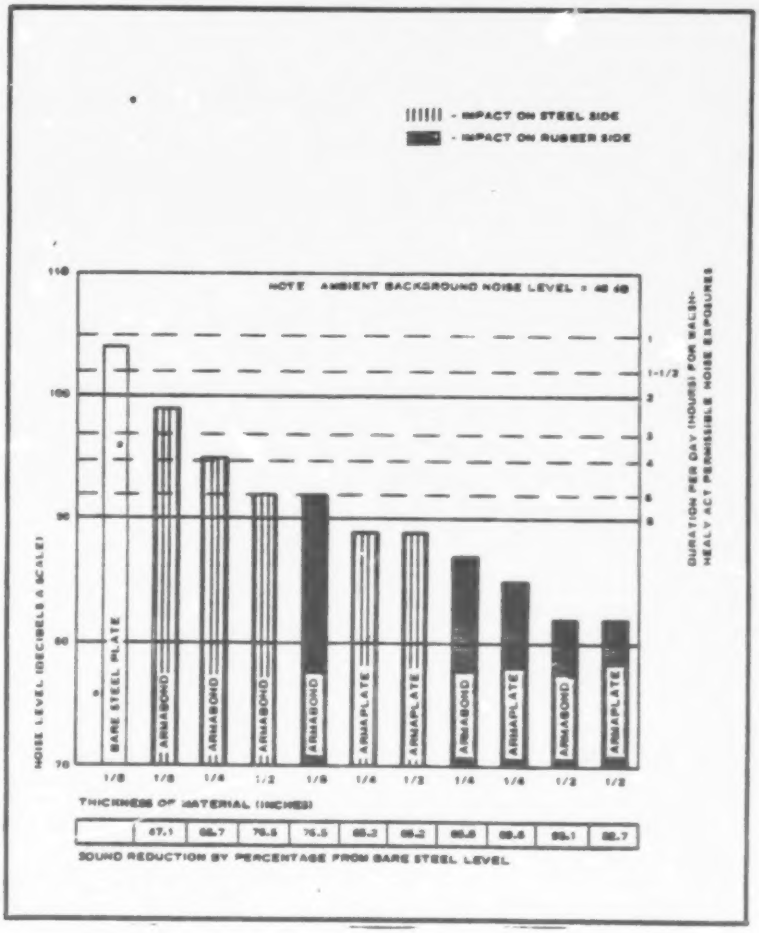


Figure 52: Effectiveness of Armabond and Armaplate Sheeting in Reducing Noise Level of Bare Steel.

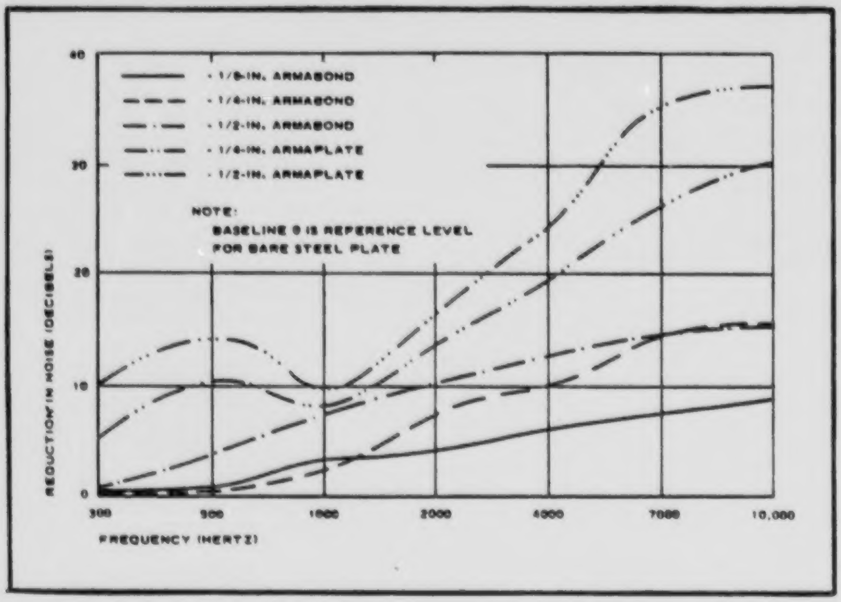


Figure 53: Frequency vs Decibel Reduction - Impact on Steel Side.

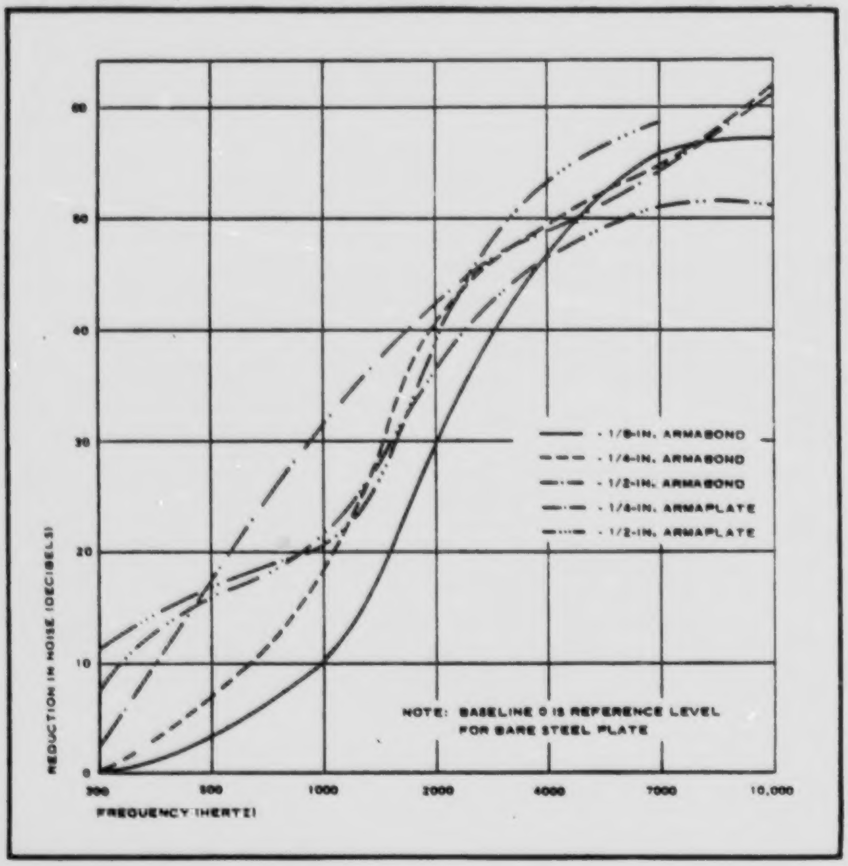
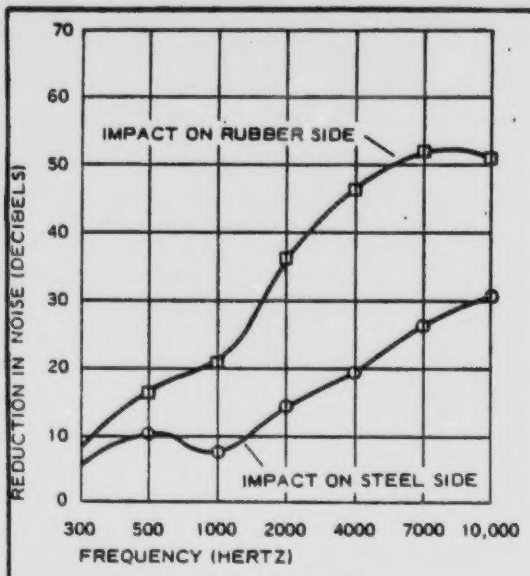
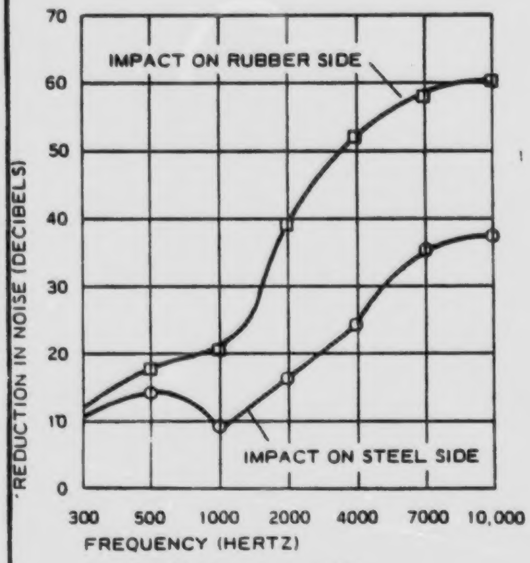


Figure 54: Frequency vs Decibel Reduction - Impact on Rubber Side.



A. ARMAPLATE 1/4 IN. THICK

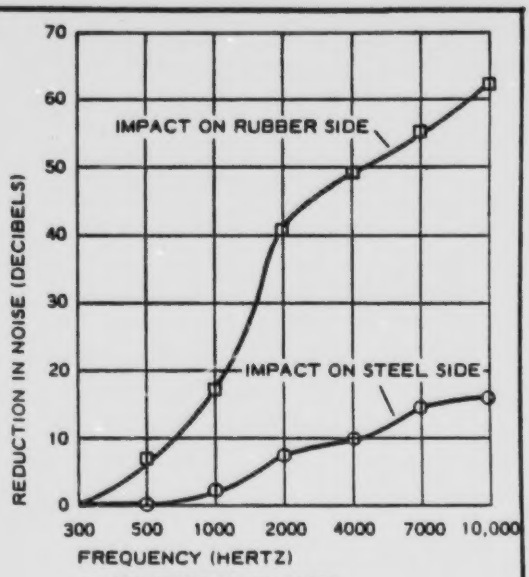


B. ARMAPLATE 1/2 IN. THICK

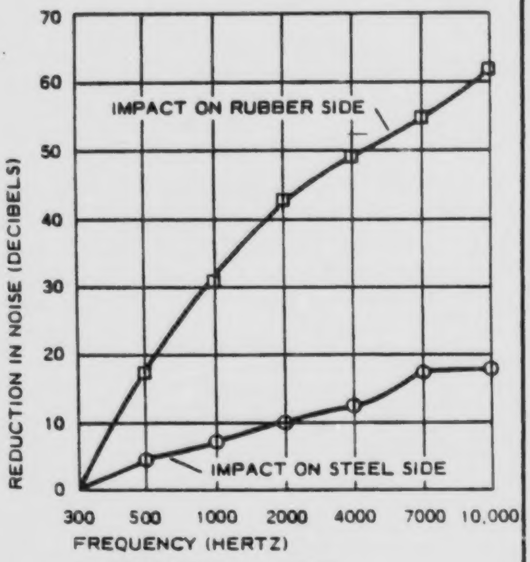
NOTE:

BASELINE 0 IS REFERENCE LEVEL
FOR BARE STEEL PLATE.

Figure 55: Frequency vs Decibel Reduction - Armaplate.



A. ARMABOND 1/4 IN. THICK



B. ARMABOND 1/2 IN. THICK

NOTE:

BASELINE 0 IS REFERENCE LEVEL
FOR BARE STEEL PLATE

Figure 56: Frequency vs Decibel Reduction - Armabond.

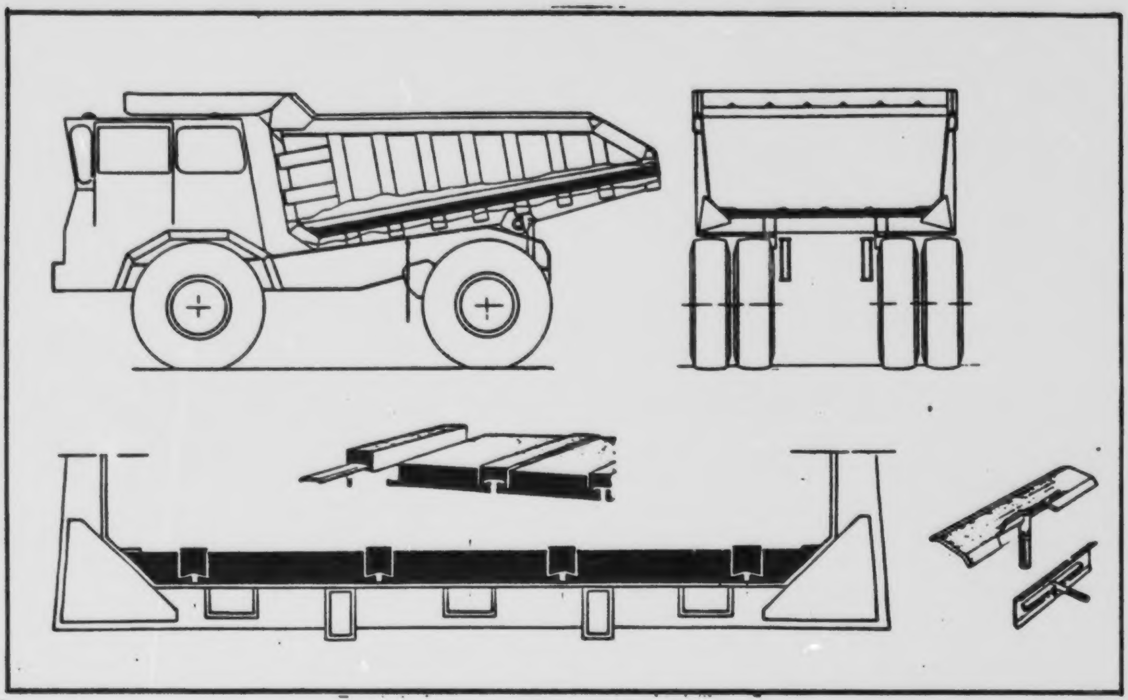


Figure 57 : A - The Truck Lining B - T-Bolt to Secure Elements.

Impact stress when loading and abrasive wear when unloading is one problem which can be overcome by the use of rubber elements on wear surfaces.

This feature provides the following advantages:

1. No impact damage, not even cubic-yard sized boulders dumped from buckets.
2. Truck axles and bearings are better protected when material is dumped from a great height.
3. Abrasion during tip dumping is reduced to a minimum.
4. The elasticity of the rubber eliminates the risk of material sticking to the lining.
5. Noise is reduced.

Practical tests with rubber-lined Granby cars show positive results.

In 1957, the bottom plate of a Granby mine car (Figure 58) was lined with 3 in. thick rubber, and was used for four years before requiring replacement.

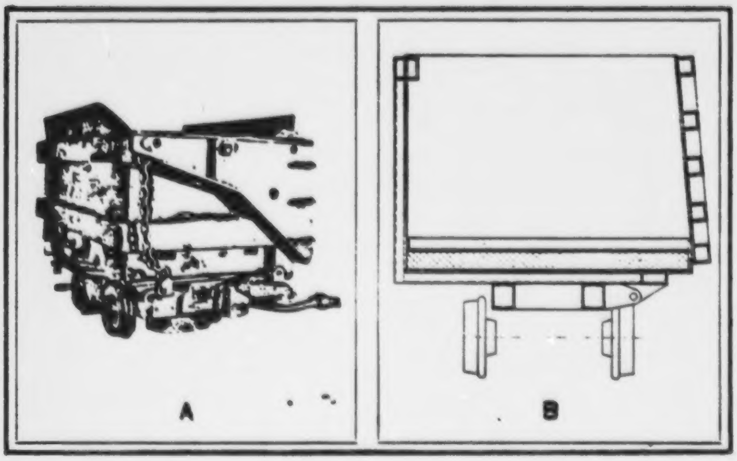


Figure 58: A. Granby Mine Car. B. Cross-section of the Car.

The advantages in this instance are as follows:

1. The long life obtained reduces costs per ton of ore transported.
2. Lower truck maintenance costs; the rubber absorbs to a greater extent the shock impact which would have been taken by the axles and bearings.
3. The use of rubber prevents clogging and build-up of material in the truck and thus saves the labour cost of removal.
4. Noise is reduced.

Other Applications of Interest

We have some different designs of rubber-lined washing drums in the mining, stone, gravel, and sand industries. This is the case in the gravel industry in United Kingdom and France.

8.5. Impact Protection with Rubber Cushioning Units

In 1936, after a number of years of research and testing the first rubber cushioning device was made. Its function was to cushion end-to-end shocks encountered between locomotives and cars. Today, nine out of ten heavy diesel road locomotives are equipped with rubber cushioning devices. Following the success of this application, the devices were applied to railroad freight and passenger cars, mine cars and industrial cars.

In 1952, the same principal was used for rubber load suspension on mine and industrial cars (Figure 59). Each year since, additional hundreds of applications have been incorporated into new mine car designs and upgrading of older cars (82).

The snubbing effect of rubber units compared to the conventional steel coil spring is characteristic of these devices. Lateral and longitudinal oscillations can be reduced by the use of rubber-cushioning units.

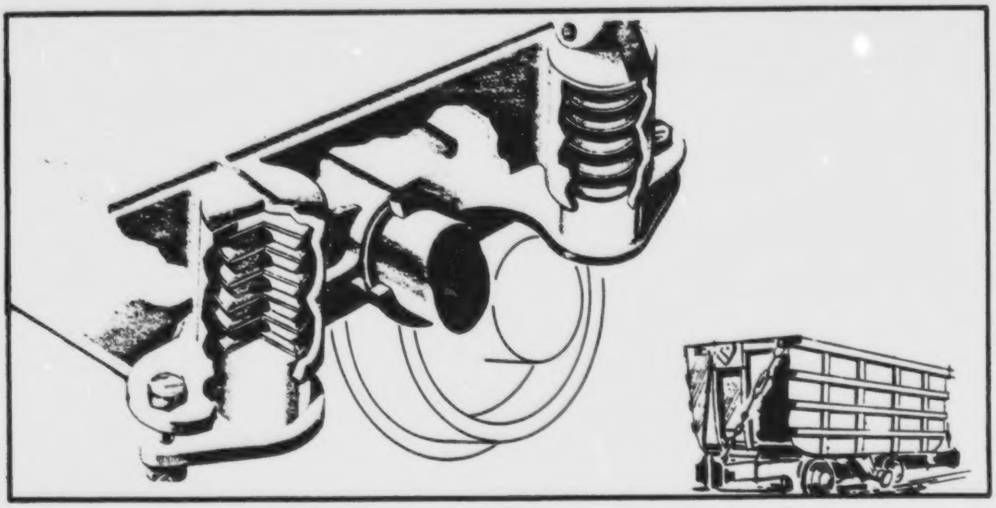


Figure 59: Integrally-Cast Suspension Housings in Canadian Cars.

Designing new applications is very simple and has universal application to fit car construction, loads, and operating conditions. Enclosed are sketches which show that the application is simple and can be applied in every place without great effort:

1. - Buffer assembly Type M1-240-7
   - Unloader bumper assembly Type M1-241-5
2. - Bridge bumper assembly Type M1-244-14
3. - Bridge bumper assembly Type M1-241-16

8. 5. 1 Mine Car, Mine Locomotive and Man Cage Applications

This application of the rubber-cushioning unit was designed to replace steel load springs formerly used in large capacity mine cars. The use of this rubber-cushioning unit has resulted in greater car stability during haulage and greater impact protection during loading operations.

The design places the load suspension units above mine dirt and moisture. Link and pin coupling: the magnitude of the forces transmitted to the car structure will be greatly reduced by the use of rubber units (Figure 60).

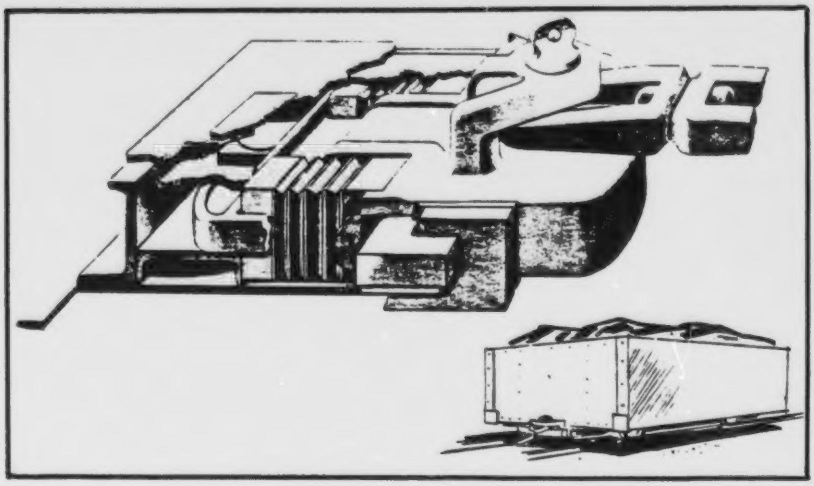


Figure 60 : Link and Pin Coupling.

8.5.2 Industrial Applications

a) Heavy duty cushioning for requiring high capacity shock.
b) Versatile high capacity shock absorption has been used in steel mill service as a vibrator shock absorber.
c) Ingot mold cars, eliminated metal-to-metal contact.
d) Locomotive crane application, consisting of rubber cushioned unit to replace helical load spring on a 109-ton diesel locomotive crane.
e) Crane buffers (in steel mill service).
f) Multiple Units - High capacity used to prevent damage to a 150-ton ore transfer car.
g) Torgue arm - motor suspension, the ideal load-travel characteristics of rubber units allow a low initial resistance which increases with the motor load (Figure 61). The rubber unit in this case has considerable impact protection.

From the above description it can be seen that the rubber cushioning units have a good technical application and at the same time, reduce impact noise.

8.6 Noise Barrier Materials

Cominco has acquired an extensive background in the field of noise control. Much of this was gained by the development of sheald barrier material (new product) (83).

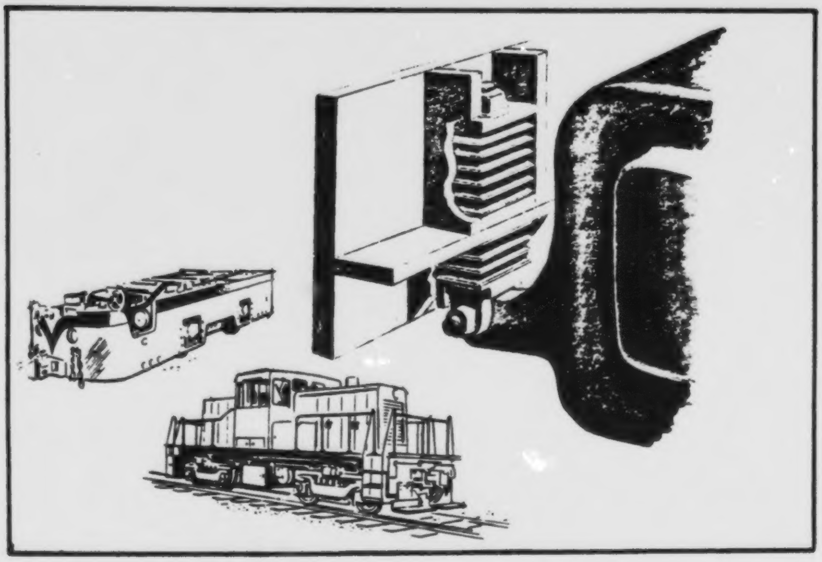


Figure 61 : Torgue Arm - Motor Suspension in this Case has Considerable Impact Protection.

Sheald Noise Control Products offer maximum performance in all three areas:

- sound attenuation,
- sound absorption,
- vibration damping,

with maximum performance and with minimum thickness and weight.

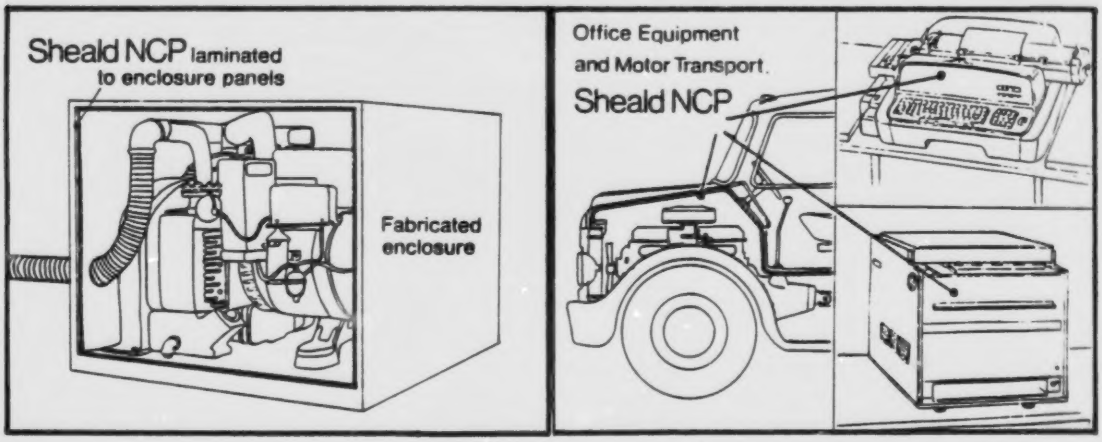

Sheald NCP laminated to enclosure panels
Fabricated enclosure
Office Equipment and Motor Transport.
Sheald NCP

Figure 62 : The Sheald NCP Noise Barrier Materials for Industrial and OEM Applications.

1) Sheald Noise Control Product I (NCPI) consists of 1 lb/sq ft (1/64 in. thick) lead to which is laminated 1 in. of polyurethane foam. The sheald provides an effective barrier to noise transmission while the foam absorbs energy (84).

Frequency - Hz	63	125	250	500	1000	2000	4000	8000	dBA
Noise level before treatment - dB	71	82	91	94	95	102	100	86	105
Noise level after treatment - dB	60	63	69	70	68	66	59	52	72
Noise reduction - dB	11	19	22	24	27	36	41	34	32

2) Sheald Noise Control Product II (NCR II) is a sandwich combination of 1 in. foam, 1 lb/sq ft (1/64 in.) lead and 1 in. of foam with a special plastic facing. This plastic, being tough resilient material adds to the strength of the product and protects the foam, from oil or other fluid (84).

Frequency - Hz	63	125	250	500	1000	2000	4000	8000	dB(A)
Noise level before treatment - dB	71	82	91	94	95	102	100	86	105
Noise level after treatment - dB	59	65	69	68	58	57	53	48	68
Noise reduction - dB	12	17	22	26	37	45	47	38	37

Noise reduction is achieved by the installation of a typical 24 gauge steel machine enclosure, measuring 24" x 24" x 30", lined with NCPI or NCPII. Comparable noise reduction can be achieved using other gauge steels, 1/2" plywood, etc...

3) The sheald NCR series of Noise Control Products were developed to meet the demand for effective, efficient noise barrier materials for industrial and OEM applications (Office Equipment and Motor Transport) (Figure 62).

Sheald NCPI is used effectively to reduce excessive noise level in motor housing generators, compressor enclosures, ducts or high pressure pipe line. Sheald NCPII can be used most effectively to reduce noise levels in highway and off-highway equipment where noise seriously impedes operator efficiency.

Cominco offers technical assistance and consultation to its customers in the selection and use of sheald noise control products.

Observations: New Cominco products offer the possibility of full control of noise in industrial fields. The product prices are high:

Noise Control Product (sold in full rolls only)	Per Carton (3' x 10')
NCPI	$58.00
NCPII	$76.00

Cominco is the only producer of these products in Canada.

8.7 Vibration Isolation

Reduction of vibration is a means of decreasing transmission of vibratory motions or forces from one structure or material to another. There are two types of vibration isolation applications:

1) those to prevent transmission of unbalanced forces from a machine to its foundation;
2) those to reduce the motion transmitted from a substructure to a sympathetic device mounted on it.

Four resilient materials are most commonly used in vibration isolators:

1) Metal Springs: These are by far the most commonly used to isolate delicate scientific instruments from foundation vibrations. Some resilient mountings are fabricated with a metal spring inside a rubber gland with a calibrated orifice which regulates the flow of air in an out of the gland thereby furnishing viscous damping.
2) Rubber Mountings: These are used very effectively to isolate small machinery and mechanical devices such as engines, motors, instruments electronic gear, etc. Rubber in compression is used widely for applications which require high energy-storage capacity and an ability to support heavy loads without failure.

3) Cork: This is one of the oldest materials used for vibration isolation. Cork is used in compression or in combination of compression and shear. The dynamic properties of cork are also very much dependent upon frequency. The pressure to which the cork should be subjected for optimum performance is between 7 and 20 psi.
4) Felt: By using felt as a vibration isolation material, the greatest isolation efficiency is obtained when using the smallest possible area of the softest felt. It has a high damping factor and thus is particularly useful in reducing amplitude of vibration at resonance. Felt is particularly useful in reducing vibration transmission in the audiofrequency range since it offers a large impedance mismatch to most engineering materials.

Principles and general practical methods for effecting vibration isolation have been considered. To decide what method to use for a specific problem one must consider cost, space, degree of isolation required, availability, reliability and other factors.

As far as rock drills are concerned there is a great tendency at the present to change from machines held by hand to machines on stands. However, it is estimated that at least 25 percent of those held by hand will still be used in the future.(85).

All of the experiments produced vibrations which were of a similar nature. This was observed in experiments carried out under widely varied conditions:
1) operating the drill at no-load,
2) drilling horizontally, and
3) drilling vertically down.

Immediately this suggest that since the vibrations in the drill are all similar, they can be effectively isolated from the handle by using suitable vibration isolators. There is one major difficulty associated with the practical use of this system; the attachments must not interfere with the operator's control over the operation of the drill. Meanwhile attempts are made to protect the hands by using different materials in the handles. Much has been achieved at Malmberget by furnishing drillers with chamois gloves to be worn inside rubber gloves (86). In this way the hands are kept warmer and it should be possible to protect them from chilling with soft inner gloves.

8.8 Aerodynamic and Hydraulic Noise

The aerodynamic and hydraulic noise, the most important source of noise is turbulence; it has been pointed out previously how this generates high noise level in fans, compressors, piping and valves.

Centrifugal and axial flow fans handling large quantities of air or gas in industrial installations can generate much noise.

The aerodynamic noise of a fan can best be described as the superimposition of discrete tones on a broad band noise.

Broad band noise is caused by a rotating fan impeller creating air turbulence as vortexes are formed at the edges of each blade of the impeller. These vortexes are random in nature, hence, the broad band noise spectrum. Discrete tones are caused by the interaction of the impeller and its housing and by the transfer of energy from the impeller blades to the air.

In order to provide adequate noise control for some fans, it may become necessary to place attenuating elements in the part of the inlet or discharge to control air-borne noise. These elements may take various forms, such as absorptive passages and/or reflective baffles.

Dissipative mufflers (Figure 63) have relatively wide-band, noise-reduction characteristics, and are usually applied to noise control problems associated with continuous noise spectra, such as fans, centrifugal compressors, jet engines, and gas turbines (71). They are also used in cases where a narrow-band noise predominates, but the frequency varies because of a wide range of operating speeds.

The acoustic performance of a dissipative type muffler depends upon its dimensions, internal arrangement and the kind of absorptive material used. It is extremely important to correlate the acoustic performance with the flow rate through the muffler. Therefore the muffler manufacturer must be given accurate information conerning velocity, pressure drop permitted, gas temperature, etc.

If a silencer is installed directly at the fan inlet, a proper design must provide evenly distributed flow across the face of the inlet. The parallel baffle or concentric ring type silencer with modified evasering type exit configuration (Figure 64) can insure uniform inlet flow.

The basic aerodynamic requirement for a fan silencer is that it not increase the air turbulence which would otherwise exist without a silencer in place (Figure 65).

Any propeller or axial flow type wheel imparts a rotating or screw action to the leaving air. At low pressure, this type of air flow straightens out in a short distance from the impeller in the tubeaxial fan. The tubeaxial fan (Figure 66) is available in direct drive construction with the wheel overhanging the motor shaft.

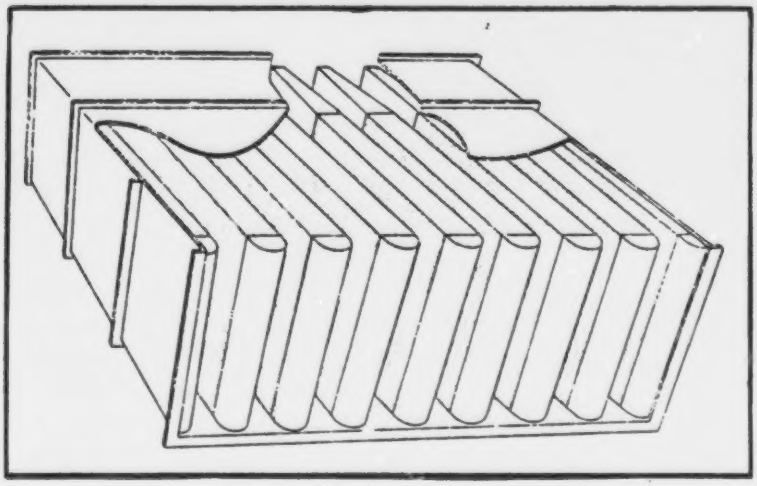


Figure 63 : Dissipative Muffler.

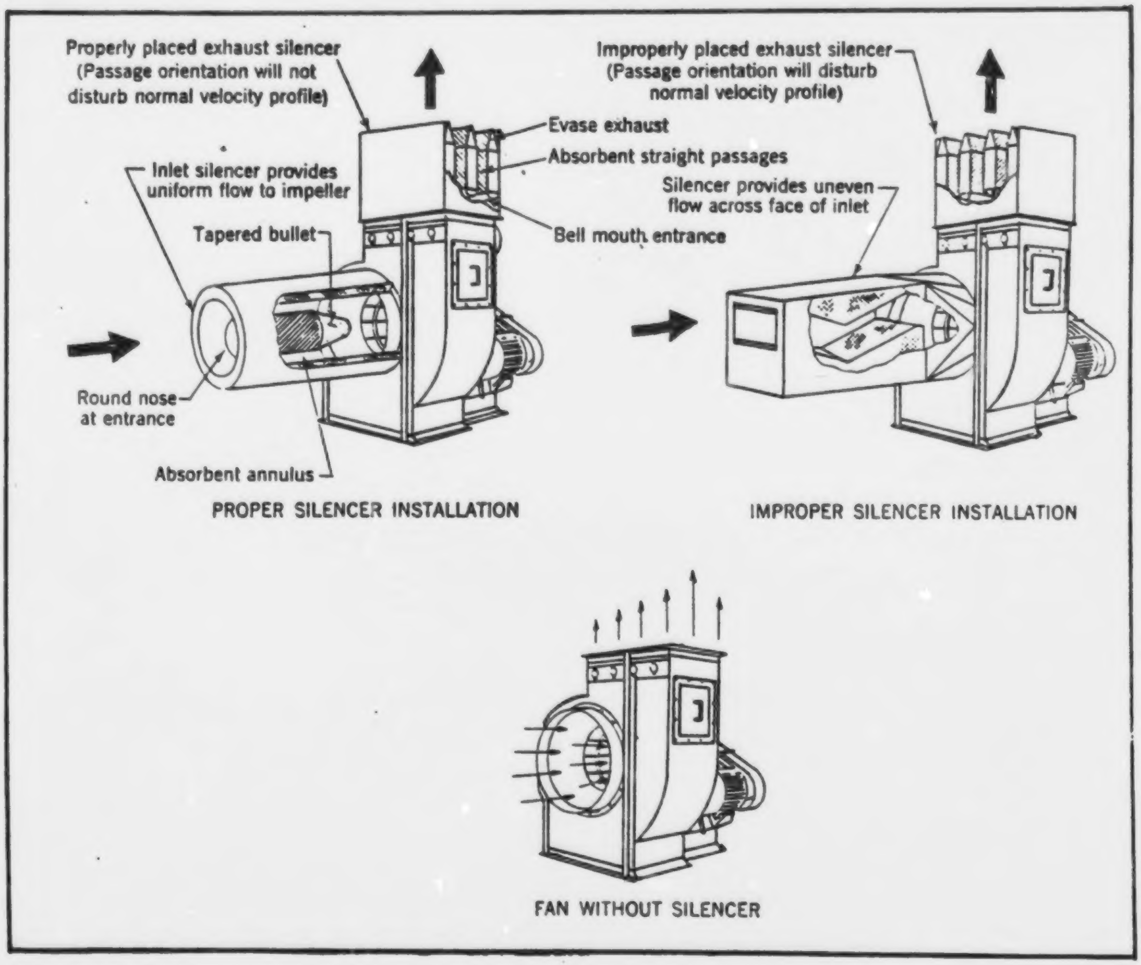

Properly placed exhaust silencer (Passage orientation will not disturb normal velocity profile)
Evase exhaust
Absorbent straight passages
Inlet silencer provides uniform flow to impeller
Bell mouth entrance
Tapered bullet
Round nose at entrance
Absorbent annulus
PROPER SILENCER INSTALLATION
Improperly placed exhaust silencer (Passage orientation will disturb normal velocity profile)
Silencer provides uneven flow across face of inlet
IMPROPER SILENCER INSTALLATION
FAN WITHOUT SILENCER

Figure 64 : Installation of Fan Silencers.

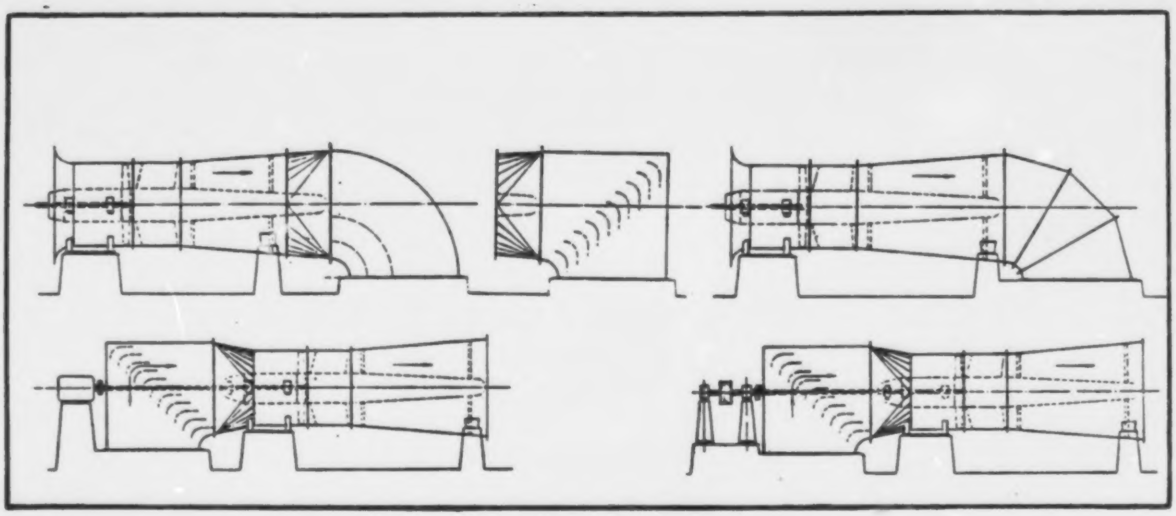


Figure 65: Air Turbulence at Elbows is a Possible Source of Ventilation System Noise.

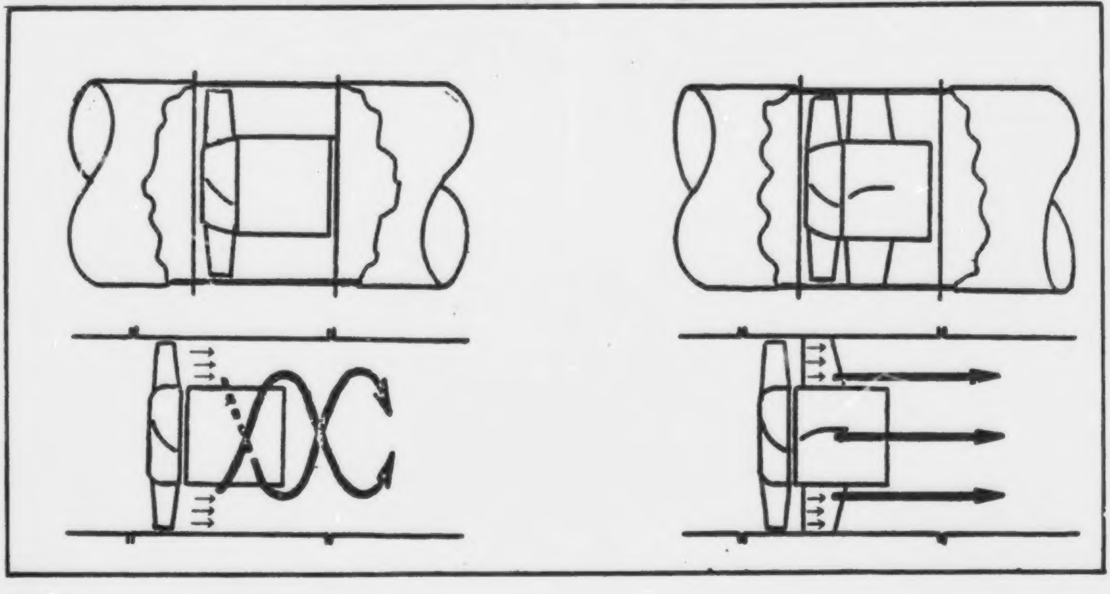


Figure 66: A Tubeaxial Fan; B Vaneaxial Fan.

With stationary guide vanes located directly behind the fan wheel, air turbulence is reduced substantially and rotative energy imparted to the air by the wheel is recovered partially. The result is an increase in efficiency and with a straight "Bee-Line" air flow leaving the fan for quieter operating conditions (Figure 66 B).

Gulf Oil Canada this summer completed a $150,000 programme to reduce noise from the Port Moody refinery near Vancouver. The various measures include: new smokeless flare tip (Figure 67) with outer ring of pipes for aspirating air; muffled exhaust vent and intake silencer for catalytic cracking unit; acoustically-lined housings on boiler forced-draft fan intake; crude oil heater burners, high speed pump, large electric motor in crude oil unit, burners in the reformer heater; sound-deadening wall on the compressor buiding; a wooden wall on the compressor building and a wooden wall 180 ft long and 20-40 ft high to keep the pumphouse and water cooling tower noises from residences across the street (86).

Most fan manufacturers can furnish the sound power levels of their fans under different operating conditions. These power levels are determined by the established methods outlined in the AMCA Code (Bulletin 300) and the ASHRAE Standards (ASHRAE Standard 36-62).

The sound analysis of a ventilating system can be divided into four parts (87):

a) the sound power source, which is the fan;
b) reduction of sound power through the distribution ducts due to acoustic losses;
c) the characteristics of any barriers between the source and the complaint area;
c) the resultant sound pressure levels in the ventilated zones.

Figure 67: New Smokeless Flare Tip.

Figure 68 contains illustration and information pertaining to units and accessories for pneumatic conveying application with silencer (88). The conveying unit with cylindrical, tapered eductor discharge silencer and a vertical, blower inlet silencer. The heavy motor base flange is extended to support the silencer and provide a compact, rigid, easily-installed power unit. This system can be used to handle all kinds of chopped metal trim or scrap. The conveyed material is blown into a centrifugal precipitator from which it is dropped out into a storage hopper.

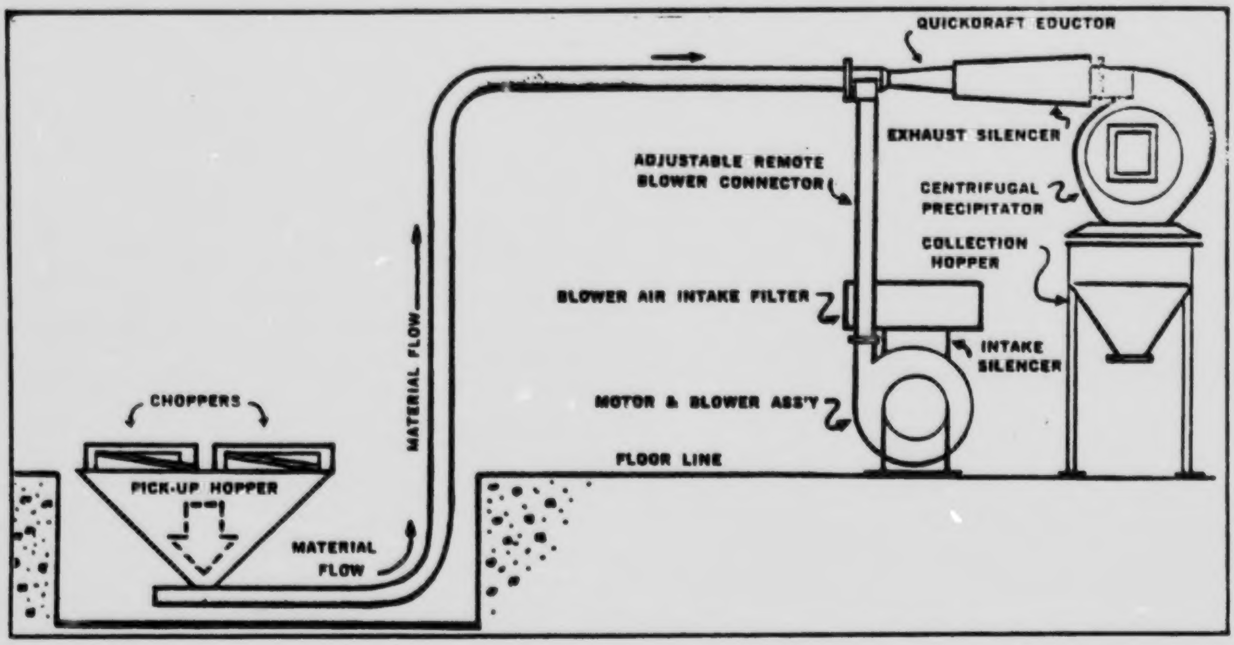

QUICKDRAFT EDUCTOR
EXHAUST SILENCER
ADJUSTABLE REMOTE BLOWER CONNECTOR
CENTRIFUGAL PRECIPITATOR
COLLECTION HOPPER
BLOWER AIR INTAKE FILTER
INTAKE SILENCER
MOTOR & BLOWER ASS'Y
FLOOR LINE
MATERIAL FLOW
CHOPPERS
PICK-UP HOPPER
MATERIAL FLOW

Figure 68: Chopped Trim Conveying System.

The piping cushion and clamp assemblies eliminate metal-to-metal contact on machinery piping installations. The cushions are made of a special plastic composition to absorb hydraulic shock and dampen machine noise caused by vibration and fluid surge (Figure 69).

In both centrifugal and axial pumps noise due to turbulence will be produced by any obstruction in the inlet or discharge that interferes with the airflow. This is one of the most important factors in centrifugal pump noise generation, and in the production of pressure pulsations in the fluid.

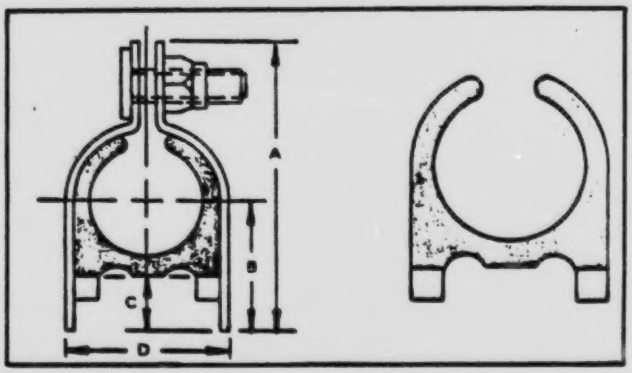


Figure 69: The Piping Cushion - Clamp Assembly.

Bends inside the pump, or changes in flow direction, are additional sources of turbulent noise. That is, the entire internal flow path should be aerodynamically designed for minimum noise generation. This includes (71):

1) keeping the flow path as large as possible to decrease velocities, and as short as possible to reduce friction;
2) removing all unnecessary obstructions;
3) maintaining smooth surfaces; and
4) providing gradual changes in flow path cross section.

8.9 Electro-Magnetic Noise

In the big mill plants and flotation mills, especially in the case of a large number of electro-motors and flotation cells, the noise from electrical machines is very hazardous. Electric motor noise often is a major factor in motor driven pump and compressor machinery. In such halls the average intensity of noise is about 100 dBA and prevents normal conversation.

There are four major sources of motor noise.

1. Flow noise consists of noise generated by the cooling air stream plus that caused by the fan.
2. Rotor noise is caused by the rotating open slots.
3. The source of noise due to electrical design is the combination of rotor bars and stator slots.
4. Mechanical factors responsible for excessive noise include misalignment of frame and end bells, which distort the frame and bearing, dynamic unbalance, noisy bearings and structural resonances.

Now in production in great series are motors with noise isolation (acoustic enclosure) and double row bearings. This is because the new regulations in some industries state that only silenced motors can be sold.

The electric motor industry and applicable standards organizations have prepared noise limit criteria that may be used as guidelines in determining where standard machines are satisfactory or where special noise control requirements should be considered. Noise limits in terms of A - weighted sound power levels (dBA re 10^{-12} watts) have been established by NEMA (National Electrical Manufacturers Association) for T-frame motors. These values are generally not exceeded by available 3600 and 1800 rpm motors.

TABLE 20

NEMA Recommended A-weighted Sound Power Level (dBA re 10^{-12} watts)

	Drip Proof		Totally Enclosed Fan Cooled	
Synchronous Speed rpm	HP	Power Level	HP	Power Level
3600	1.5/2/3	76	1.5/2	88
	5/7.5	80	3/5	91
	10/15	84	7.5/10	94
	20/25	87	15/20	98
	30/40	90	25/30	100
	50/60	94	40/50	103
	75/100	98	60/75	105
	125/150	102	100	106
	200/250	105	125/150	107
1800	1/1.5/2	70	1/1.5/2	74
	3/5	72	3/5	79
	7.5/10	76	7.5/10	84
	15/20	80	15/20	89
	25/30	83	25/30	92
	40/50	86	40/50	97
	60/75	89	60/75	100
	100/125	92	100	102
	150/200	94	125/150	104
1200	Being established by subcommittee			
900	Being established by subcommittee			

In Table 20, reference is made to two types of enclosures: drip-proof and totally enclosed fan cooled (89). The drip-proof motor pulls air from the motor's external environment and circulates the air around the electrical conductors, removing heat close to the source of generation and expelling it via the frame. The totally-enclosed fan cooled draws air into the chamber by means of a fan mounted external to the motor and blowing air over the surface of the motor.

The Westinghouse Electric Corporation, the line of TEFC (Totally-Enclosed Fan Cooled) motors have been specially designed to minimize noise generation.

TABLE 21

Maximum Sound Levels at 3 ft (dBA re 20μ N/m^2) and Maximum Sound Power Levels (dBA re 10^{-12} watts) of Westinghouse Standard Motors

	Drip-proof			Totally Enclosed Fan Cooled		
Synchronous Speed rpm	HP	Sound Level	Power Level	HP	Sound Level	Power Level
3600	1.5 to 250	59 to 88	65 to 97	1.5 to 105	73 to 90	78 to 100
1800	1 to 200	54 to 76	60 to 85	1 to 150	58 to 91	63 to 101
120	0.75 to 125	54 to 77	59 to 87	0.75 to 125	54 to 82	60 to 93

The noise emanating from a TEFC motor results from blowing air over the external cooling surfaces. Air noise is dependent upon the velocity of the air and the openings and obstructions it passes through. The size of the fan number of fan blades and exhaust openings and the contour of the external cooling surfaces are also design variables which must be taken into account.

Other considerations were to add more copper and iron to the machine to reduce losses and the insulation was changed to allow a higher temperature rise. Iron was used for the frame structures to reduce structural resonances.

The Drip-proof (DR PR) motors produced less noise than TEFC motors. These motors are rarely installed in close proximity to personnel.

General Dynamics designed a new quiet induction motor for centrifugal compressor drives (90). The new 700 HP motor has special terminal box registers 73 dBA, 1000 Hp, 82 dBA and 1500 HP at the same 82 dBA level. All levels were taken 5 ft from the motor during no-load operation. The new motor features low vibration and top air-intake discharge. In the past, air inlet and discharge for open, drip-proof or weather-protected motors were in direct line of site, with regard to noise sources as potential observers ear position. Now, the first objective was to remove this direct line of site between source and observer. Secondly, low frequency or long wavelength noise was to be abated by the use of acoustical absorption materials. Thirdly, since higher frequencies, with the associated shorter wavelengths, are able to be effectively trapped within small airduct passages, airflow paths were provided for a natural attenuation of these higher-frequency noise sources.

Expansion of population centres into areas near existing industrial and mining facilities is creating complaints about noise where none previously existed. One of the best examples is the power station. To reduce the noise in community centres and working places near power stations. acoustic enclosures are built in (Figure 70).

In the case of power stations of great power force, buildings are constructed which have all the security installations and complete acoustical isolation.

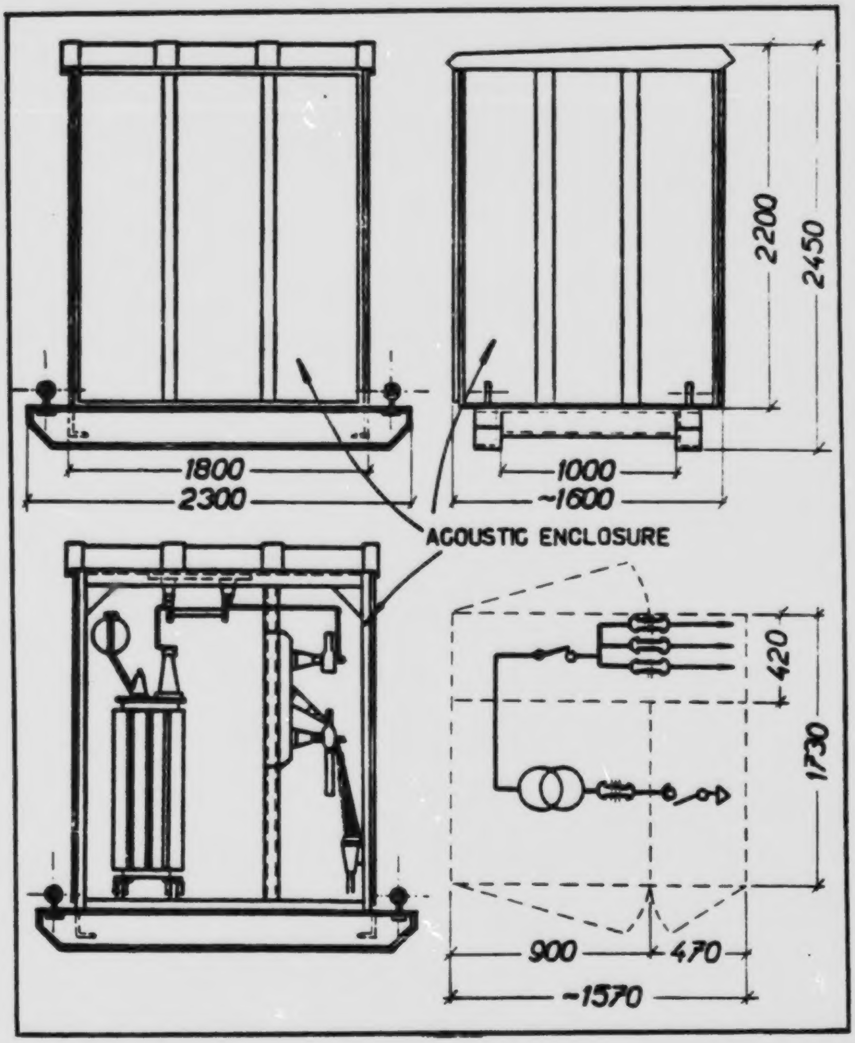

2200
2450
1800
2300
1000
~1600
ACOUSTIC ENCLOSURE
420
1730
900
470
~1570

Figure 70: Power Station 100 KVA.

9. FUTURE RESEARCH

9.1 Projects

The future development of the acoustics laboratory in the Mining Research Centre can be divided into two steps.

The first four projects of the first step produce great benefits with very low investment. The projects must be finished within 2 years and give the basis for future work. The investment in instruments is about $8000. Expected benefits are:

1. The standardization of the measurement and of the measurement technique;
2. The introduction of the administrative control of the miners who are exposed to noise;
3. Engineering control, noise reduction at the source and of the transmission parts;
4. Effects of noise and vibration on man;
5. Technical solutions and consulting.

The second step is much more difficult and is composed of fundamental research and of complete technical solutions as project five. Instruments in this step of research will cost about $40, 000.

It is possible to do parallel work but with more men and greater investment in instruments and supplies.

PROJECT 1

TITLE: Noise survey in Denison Mines
(Comparison Measurement Techniques)

OBJECTIVES: To determine the noise level to which underground mine employees are exposed, to compare the new noise pocket dosimeters with standard techniques in a mining situation, and to evaluate noise exposures using the Walsh-Healey criteria adopted by ACGIH for 1969.

OUTLINE OF WORK: To determine noise exposures for assessment of environmental noise, two variables must be observed:
1) sound levels (we will use Sound Level Meter);
2) the time of exposure per shift at each sound level observed (we will use the noise pocket dosimeter).

Both instruments will operate on the A-weighted and slow response, and will be acoustically calibrated in accordance with the manufacturer's instructions before and after each shift.

The partial-shift time of exposure will be determined by the sound level meter; and full-shift studies will require the recording of the operations for one occupation for the entire 8-hour period. The A-scale has received wide interest as a simplified method for evaluating noise exposures with readily-available commercial instruments.

On the author's request, G. R. gave the following data:
1) Accuracy comparison between sound level meter and 1944 noise dosimeter;
2) Sine wave frequency response error for 1944 in free field 60° incidence;
3) 1/3 octave noise frequency-response error for 1944 in reverberant room;
4) 1/3 octave noise frequency-response error for condenser microphone;
5) Maximum perturbations in response to pink noise, measured in third octave bands from 250 Hz to 8 k Hz, caused by a nearby person;
6) Maximum perturbations in response to pink noise, measured with A-weighting, caused by a nearby person.

We have shown that the noise dosimeter can be a very accurate instrument even though it is small. By itself it is twice as accurate as the sound-level meter.

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2. Lamonica, J. A., Mundell, R. L., and Muldoon, T. L., "Noise in Underground Coal Mines, Report of Investigations 7550". USA Bureau of Mines.
3. Murphy, J. N., Sacks, H. K., Durkin, J., and Summers, "Progress in Noise Abatement", Mining Congress Journal, September (1972).
4. Schneider, H. J., "Microphone Orientation in the Sound Field", Sound and Vibration, pp 20-25, February, (1970).
5. General Radio, data from sales literature in 1972.

EXPECTED BENEFITS:

1) To compare the two types of instrument and noise exposure assessment technique in mining situations using Walsh-Healey Act.
2) To collect data and start working on lowering the OSHA table, to begin with 8 hours at 85 dBA.

WORK SCHEDULE:

Testing GR 1944 Noise-Exposure Monitor and GR 1944 Noise-Exposure Indicator in Denison Mines (underground)------------------ 10 days

STAFF:

Professional	- Field	10 days
	- Office	5 days

EQUIPMENT:

General Radio	
GR 1944 Noise - Exposure Monitor	$350.00
GR 1944 Noise - Exposure Indicator	$495.00
	$845.00

PROJECT 2

TITLE: Noise in Canadian Mines

OBJECTIVES: The objective of this study is to identify the specific noise sources for noise reduction purposes. Noise control is the application of techniques to the problem to obtain the best results most economically.

1) The first objective will be to identify those occupations in which the individual's exposure exceeds the limits of the proposed noise standard for underground and surface facilities. The permissible noise exposures were published in the Federal Register (USA) and adopted by ACGIH for 1969.

2) The second objective of this study will be to identify the noise sources and to describe, through frequency analysis and impact noise, how the sound energy is distributed over the audiable range of frequencies.

OUTLINE OF WORK: To determine noise exposures for assessment of environmetal noise, two variables must be observed:
1) Sound Levels;
2) the time of exposure per shift at each sound level observed.

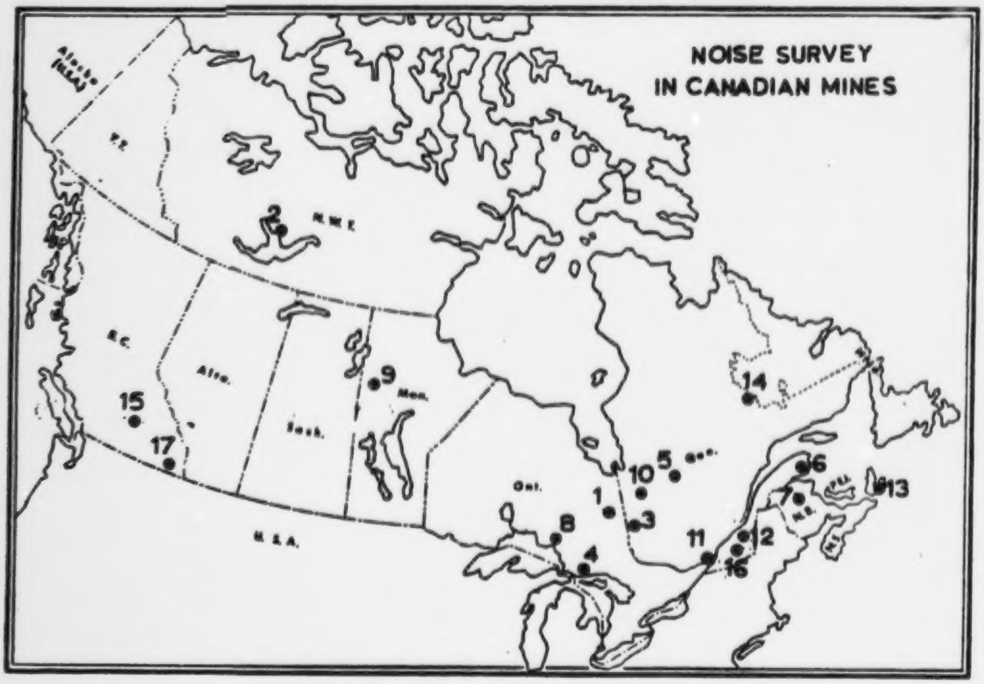
The standard technique is to observe sound levels with the sound level meter (dBA). The dBA is simply measured with low-cost instruments, and gives sufficiently useful data to define noise levels.

To determine the time of exposure per shift we will use Noise Pocket Dosimeters. Some instruments have recently been developed in which this integration is done electronically. These instruments are small and are intended to be worn by the person at risk.

At each work area, noise levels were measured, using noise pocket dosimeters and a sound level meter (dBA). Each individual will be surveyed for a full shift, each 5 minutes. Each work area will be observed and recorded with an octave band analyzer. Octave band measurements will be made at 15-to 30-minute intervals throughout the shift.

It is proposed to examine and quantify the factors in the mine environment which may explain the differences found in noise level from the same machine in different situations. Among the factors which can be expected to be important in the mining environment are mine opening size, rock type, presence of muck pile, number of machines etc.

The measurement will be made in the following mines:


NOISE SURVEY
IN CANADIAN MINES
Alaska (U.S.A.)
Y.T.
N.W.T.
B.C.
Alta.
Sask.
Man.
Ont.
Que.
U.S.A.
P.E.I.
N.B.
N.S.
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17

I Underground	Total Employees
- Gold Mines	
1. Kerr Addison Mines	404
2. Giant Yellowknife Mines	263
- Silver Mines	
3. Manitou-Barvue Mines	128
- Uranium and Thorium Mines	
4. Denison Mines	453
- Copper Mines	
5. Opemiska Copper Mines	404
6. Gaspe Copper Mines	172
- Lead Mines	
7. Brunswick Mining and Smelting Corp. Ltd., Bathurst	371
- Iron Mines	
8. Algoma Ore Div. (MacLeod)	250
- Nickel Mines	
9. Sherritt Gordon	338
- Zinc Mines	
10. Mattagami Lake Mines	229
- Other Metals Mines	
11. St. Lawrence Columbium	76
- Non-Metallics Mines	
12. Thetford Mines (King Beaver)	277
- Coal Mines	
13. Cape Breton Development Co.	1017

II Open Pits:

- Iron Ore
  14. Iron Ore Company of Canada, Labrador
- Copper Mines
  15. Bethlehem Copper Corporation Ltd., Highland Valley
- Non-Metallics Mines
  16. Canadian Johns-Manville Company Limited, Asbestos, Que.
- Coal Mines
  17. Kaiser Resources Ltd.

EXPECTED BENEFITS: The immediate benefits can be classified in three categories:

1) Administrative control is aimed at reducing the time of exposure to the noise. One technique is the rotation of personnel so that exposure in the high noise area is for a limited period of time.

2) Engineering control: - Noise reduction at the source and noise control of the transmission path, through frequency analysis.

3) Effects of Noise and Vibration on man and protective measures at the receiver.

REFERENCES:

1. Botsford, J. E., "A Simple Method for Indentifying Acceptable Noise Exposures", J. Acoust. Soc. America 42, October (1967).
2. Lamonica, J. A., Mundell, R. L. and Muldoon, T. L., "Noise in Underground Coal Mines, R. J. 7550. USA Bureau of Mines.
3. Lamonica, J. A., "Noise Levels in Cleaning Plants", Mining Congress Journal, July (1972).
4. Cannon, M. R., "Noise Reduction for Equipment Operations Underground", Mining Congress Journal, March (1972).

WORK SCHEDULE:

We will test 50 percent of the employees:

I. Underground:	Days		Days
- Gold Mines -	33	- Nickel Mines -	16
- Silver Mines -	7	- Zinc Mines -	12
- Uranium Mines -	23	- Other Metal Mines -	3
- Copper Mines -	29	- Non Metalic Mines -	14
- Lead Mines -	18	- Coal Mines (25%) -	25
- Iron Mines -	12		
			Σ 192

II. Open-pits:

	Days		Days
- Iron Ore -	15	- Non Metalic Mines	18
- Copper Mines -	20	- Coal Mines (30%) -	23
			Σ 76

STAFF:

Professional			
- Field -	268 days	- Office -	100 days
Technician			
- Field -	268 days	- Office -	100 days

EQUIPMENT:

1.	Sound and Vibration Set (B & k), Type 3507 a) Impulse Precision Sound Level Meter Type 2209 b) Third-octave and octave filter set Type 1613	-	$2,974.00
2.	1944 Noise - Exposure Monitor (9 pieces)	-	$3,150.00
		Σ	$6,124.00

PROJECT 3

TITLE: Standard Noise Generator

OBJECTIVES: During noise measurements on surface and underground the results obtained were different, due to the conditions under which the rock drill is working (reflection, air pressure, etc.). The noise increase in light- and medium- hammer drills underground can be from 4 to 8 dB. But often we wish to know the exact or approximate noise value of the hammer drill in dB.

OUTLINE OF WORK: To construct the standard noise generator on the basis of compressed air (nozzle with standard pressure gauge). The noise generator prototype should be constructed so the valve and use are accessible and simple. The noise generator will be tested at NRC. Measurement will be conducted in accordance with the standards.

REFERENCES:

1. Botsford, J. H., "Engineering Standards and Specifications", Penn State University, Seminar, June 25 - 30, (1967).
2. Compressed Air and Gas Handbook, Compressed Air and Gas Institute, Third Edition - 1961 (Revised 1966).

EXPECTED BENEFITS: To compare the noise produced by the light- and medium- hammer drills on surface and underground.

WORK SCHEDULE:

	Professional	Technician
1. Project (Design)	15	
2. Construction (work)		15
3. Testing	4	
4. Correction of the prototype		10
5. Final test	4	

STAFF:

Professional -	23 man-days
Technician -	25 man-days

EQUIPMENT:

Standard Pressure gauge -	$100.00

SUPPLIES:

Steel and pipes	$100.00

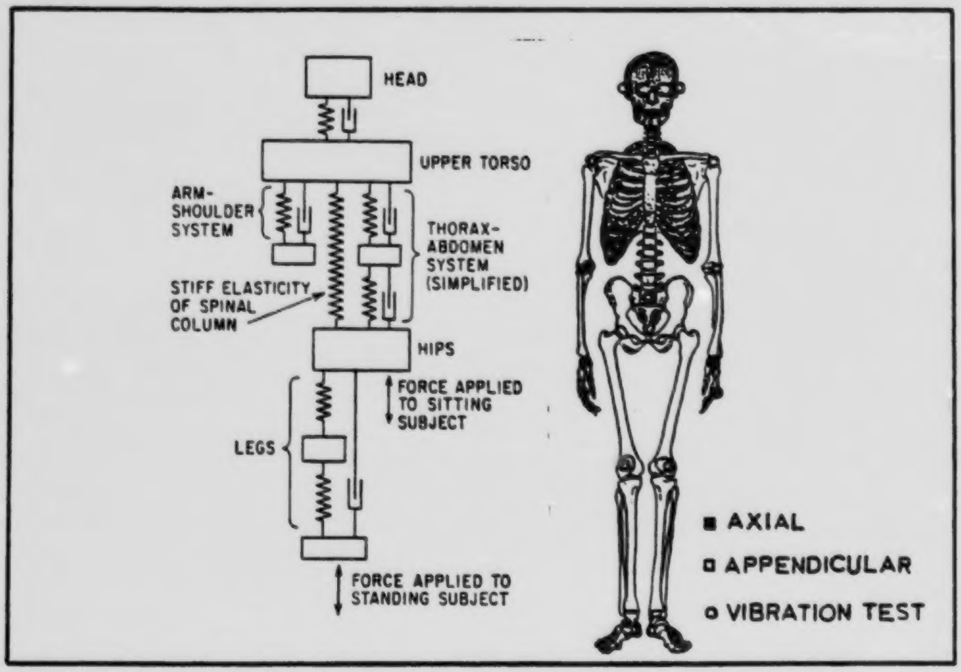
TRAVEL:

NRC in Ottawa	8 man-days

PROJECT 4

TITLE: A study on vibration in rock drills and body (axial and appendicular skeleton) during drilling.

OBJECTIVES: The effects produced by high-intensity vibration during rock drilling cause physical damage to miners hands, arms and shoulders, are damaging to morale, and detrimental to attempts to attract workers to the mining industry.


HEAD
UPPER TORSO
ARM-SHOULDER SYSTEM
THORAX-ABDOMEN SYSTEM (SIMPLIFIED)
STIFF ELASTICITY OF SPINAL COLUMN
HIPS
FORCE APPLIED TO SITTING SUBJECT
LEGS
FORCE APPLIED TO STANDING SUBJECT
■ AXIAL
□ APPENDICULAR
○ VIBRATION TEST

Axial and appendicular skeleton

OUTLINE OF WORK: The reason for this project is to establish practical relationships between rock drills and the body under normal drilling conditions, measuring the frequencies of vibrations and their corresponding displacements, velocities and accelerations.

REFERENCES:

1. Broch, J. T., "Mechanical Vibration and Shock Measurements", (1972).
2. Renard, Dr. Clair, "Vibration Injuries in the Fingers of Miners in Northern Sweden", Malmberget, Sweden, (1962).

3. Aleksaudrov, E. V., Flavickij, Jr. V., and Nikolaevskij, N. A., "Vibration measurement on pneumatic hand tools," Masinostroitel, Moscow, USSR, No. 7, pp. 41-42, January, (1968).
4. Babec, K. K. and Kulazenko, V. I., "Our experience in suppressing vibration", Bezopasuost truda v promyslenosti, Moscow, USSR, No. 11, Vol. 8, pp. 25-26, November (1964).

EXPECTED BENEFITS: To compare the frequencies of vibrations produced by rock drills and body according I. S. O. recommendation.

WORK SCHEDULE:

	Professional	Technician
1. Testing	20	20
2. Correction of the test	5	5

STAFF:

Professional	25 man days
Technician	25 man days

EQUIPMENT

1. Standard Accelerometer B & K Type 8304S	$354.00
2. Accelerometer, miniature set types 8307	$215.00
3. Vibration calibrator Type 4291	$636.00
	$1,205.00

PROJECT 5

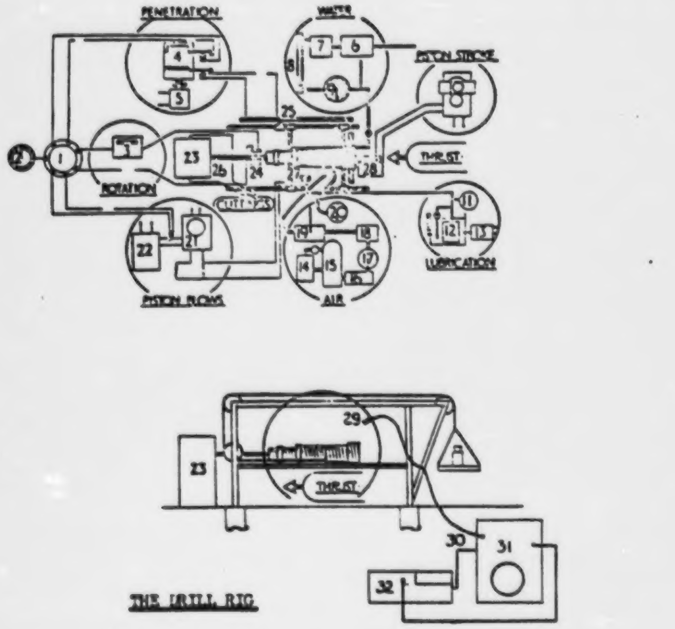
TITLE: Noise Abatement in Canadian Rock Drills.

OBJECTIVES: The noise produced by pneumatic rock drills used in underground mines is high. Several manufacturers are devoting considerable effort to control the excessive noise because of purchaser demand for quiet equipment. One of the principal noise sources is the exhaustion of compressed air. Several companies now have mufflers available which can be placed over the body of the drill. Other companies have redesigned their equipment and incorporated exhaust mufflers into their tools. Significant noise reduction has been achieved. However, the noise problem has not been solved. Even the muffled drills produce noise levels which require ear protection for the operator. The drill manufacturers realize that there is a demand and market for quiet equipment, and they are continuing their research and development of quieter tools.

OUTLINE OF WORK: The basic research work must be directed in the struggle against the noise in light and medium rock drills and if possible that they retain the same drilling performance.

The impact noise (steel noise) represents a greater problem than the exhaust noise. To assure maximum achievement in the results the following should be done:

1. To accomplish the selection of light or medium rock drills with a Canadian manufacturer and to perform on them the following principal measurements (see sketch):
    a) Penetration
    b) Air pressure and air consumption
    c) Thrust
    d) Water pressure and water consumption
    e) Noise.
2. On the basis of the results obtained to do a modification of the machine components and to repeat the measurements from a) to e). Any positive or negative differences in the measurements will justify our work.
3. To obtain very exact and sure results the drill rig must be constructed. With less accuracy the same measurements can be performed without the drill rig, and with the same instrumental system by the CAGI-PNEUROP Test Code procedure. In this case the factor "thrust" will be variable. In dependence of this factor the penetration and noise will be variable too.
4. The program will be executed in cooperation with a Canadian manufacturer.


PENETRATION
WATER
PISTON STROKE
THRUST
ROTATION
CUTTINGS
LUBRICATION
PISTON BLOWS
AIR
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THE DRILL RIG

1 Master switch
2 Stop clock
3 Rotation counter
4 Barograph drum recording penetration
5 Drive motor to recording drum
6 Water feed reducing valve
7 Integrating water meter
8 Water rotameter
9 Water pressure gauge
10 Piston stroke oscilloscope and camera
11 Oil pressure gauge
12 Oil pump, tank and by-pass
13 Oil pump motor
14 Air compressor
15 Compressed air receiver
16 Compressed air reducing valve
17 Compressed air pressure gauge at meter
18 Compressed air quantity meter
19 Baffle
20 Air pressure gauge at drill inlet
21 Piston blows oscilloscope
22 Piston blows electronic counter
23 Rock specimen
24 Make-and-break mechanism for rotation counter
25 Make-and-break slider for depth of penetration
26 Tray for collection of cuttings
27 Make-and-break diaphragm for blow counter
28 Piston stroke potentiometer

SOUND MEASURING SYSTEM

29 Microphone
30 Cable
31 Spectrometer
32 Level Recorder

REFERENCES:

1. Botsford, J. H., "Noise Abatement." Can. Min. J., October (1960).
2. Fischer, H. C., "Noise Control of Pneumatic Mining Equipment". Can. Min. J., October (1962).
3. Holdo, J., "Energy Consumed by Rock Drill Noise". Mining Mag., V. 99, pp. 73-75, August (1958).
4. Savich, M. V., "Investigation and Abatement of Noise from Pneumatic Machines". Master Degree's Thesis, McGill University, (1972).

EXPECTED BENEFITS:

1) With the construction of the integral muffler and with the built-in sound barrier, the noise will be lowered for further 3-4 dBA which is enough (in the beginning) to not affect the production of a Canadian manufacturer.

2) If the project continues in 1974 with the building of a complete measuring system then, on the basis of measurements and of new modifications of the machine components, we can expect a new lowering of noise.

WORK SCHEDULE:

	Professional	Technician
1. Testing before modification of the rock drill	5	
2. Design of the integral muffler	30	
3. Construction and built-in of the muffler		40
4. Testing after modification of the rock drill	5	
5. Correction of the prototype		10
6. Final test	2	

STAFF:

Professional	42 man days
Technician	50 man days

EQUIPMENT (see sketch):

1.	Water feed reducing valve	$750.00
2.	Integrating water meter	
3.	Water rotameter	
4.	Water pressure gauge	
5.	Compressed air reducing valve	$700.00
6.	Compressed air pressure gauge	
7.	Compressed air quantity meter	
8.	Channel selector (B & K) Type 5619	$2,010.00
9.	Microphones (B & K):	
	-Cartridges condenser Type 4133 à $232.00; 8 x	$1,856.00
	-Preamplifiers Type 2619 à $308.00; 8 x	$2,464.00
	-Microphone Power Supply Type 2807 at $574.00 each x 4	$2,296.00
	-Extension cables (30m) Type A0 0029 à $108.00; 8 x	$864.00
10.	Real-Time Analyzer (B & K), Type 3347	$14,883.00
11.	Level Recorder (B & K), Type 2307 (new type)	$3,000.00
12.	Tape Punch, Type 6301	$3,653.00
13.	Vibration Pick-up Preamplifier (B & K), Type 2625	$435.00

14. Accelerometer Calibrator (B & K) Type 4291	$636.00
15. Accessories	$25.00
16. Tape Recorders (B & K) Type 7003 and 7004	$6,000.00
	+ $2,000.00
	$41,094.00

SUPPLIES

1. The drill rig	$4,000.00
2. Pipes	$100.00
3. Rock specimen (can. Porfir)	$350.00
	$4,450.00

9.2 Electronic Instruments in Sound and Vibration

The equipment for the noise and vibration laboratory in Elliot Lake is classified according to the projects (1 - 5).

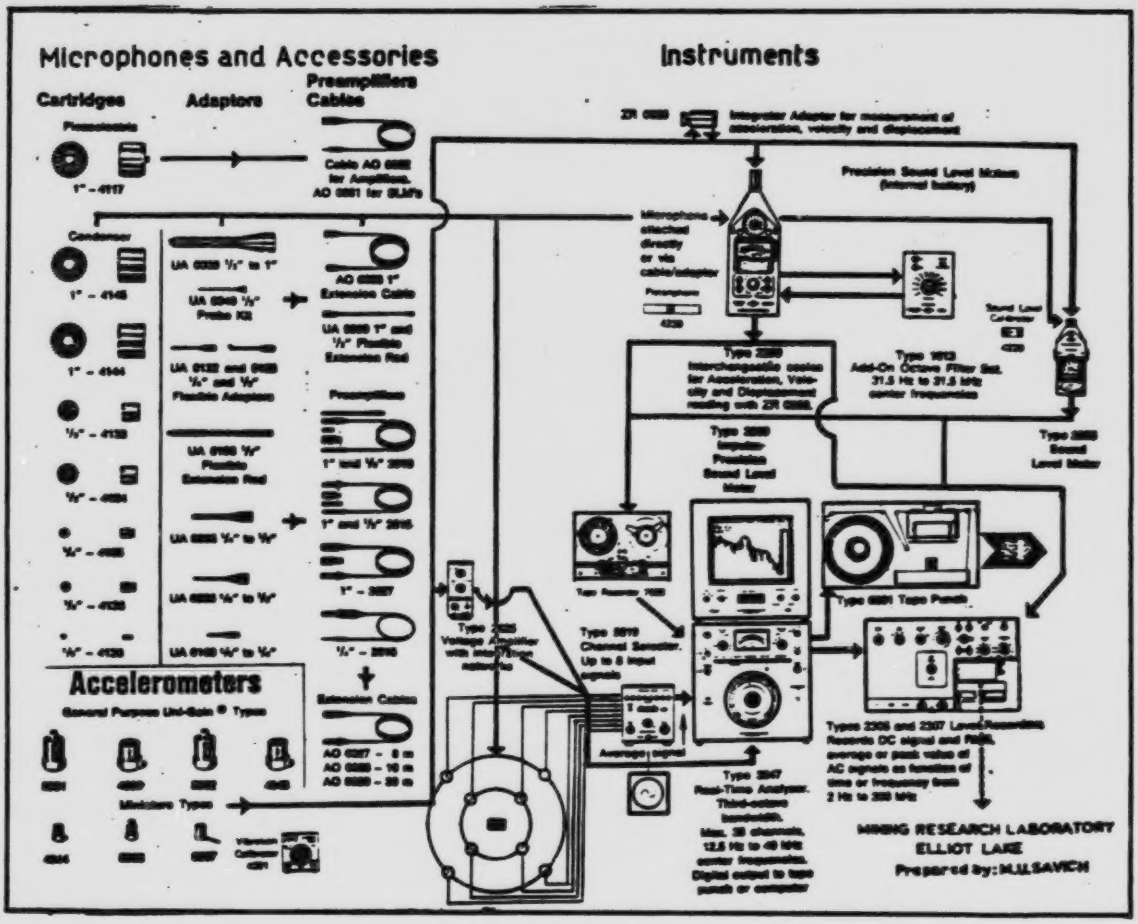
Microphones and Accessories
Cartridges
Adaptors
Preamplifiers
Cables
Condenser
1" - 4117
1" - 4145
1" - 4144
Preamplifiers
Extension Cables
Accelerometers
Miniature Types
Instruments
Precision Sound Level Meters
(internal battery)
Microphone attached directly or via cable/adaptor
Add-On Octave Filter Set.
31.5 Hz to 31.5 kHz
center frequencies
Sound Level Meter
Type 6301 Tape Punch
Channel Selector.
Up to 6 input signals
Average signal
Real-Time Analyzer.
Third-octave bandwidth.
Digital output to tape punch or computer
Types 2305 and 2307 Level Recorders
Records DC signal and RMS, average or peak value of AC signals as function of time or frequency from 2 Hz to 200 kHz
MINING RESEARCH LABORATORY
ELLIOT LAKE
Prepared by: M.U.SAVICH

Figure 71: The Instruments for Sound and Vibration Measurement, Analysis, Recording and Data Processing.

The purchase of the equipment must go step-by-step according to the development of the projects.

1973 - 1974

		Price
Project 1.	Noise survey in Denison Mines (Comparison Measurement Techniques) Sound level meter purchased November 1972.	$845.00
Project 2.	Noise in Canadian Mines	$6,124.00
Project 3.	Standard noise generator	$100.00
Project 4.	A study on vibration in rock drills and body.	$1,205.00
		Σ $8,274.00

1975

Project 5.	Noise Abatement in Canadian Rock Drills	$41,094.00
		Σ $41,094.00
	Total	$49,368.00

These investments are sufficient to finish the projects according to the foreseen plan.

REQUEST FOR EXPENDITURE
DEMANDE DE DEFENSE D'ARGENT

Mining Research Laboratory / Laboratoire de recherches minières
Elliot Lake, Ontario

TITLE/TITRE: Channel Selector Type 5619 with Microphone and Accessories

DATE: November 20/72 PREPARED BY/PREPAREE PAR: M. SAVICH COST/COUT:

PROJECT/PROJET: THE MACHINE NOISE SURVEY

PROBLEM/PROBLÈME Evaluation of collected data: Time average of Sound Pressure Level on a hypothetical hemisphere around the source. I.S.O. recommendation R 495

ALTERNATIVES CONSIDERED / AUTRES POSSIBILITÉS ENVISAGÉES: NO ALTERNATIVES

1. a) Bruel & Kjaer Type 5619 Channel Selector

   b) Bruel & Kjaer Microphones:

Condenser Microphones	Type 4133	8X
Preamplifiers	Type 2619	8X
Microphone Power Supplies	Type 2807	4X
Extension Cables	Type A00029	

JUSTIFICATION:

1. No construction of Microphone orientation system.
2. Immediate evaluation of collected data.
3. 2 to 8 channel transient free switching.
4. Ideal for Sound Power evaluation of machinery and spatial averaging.
5. Measurements may be conducted to internationally accepted procedures e.g.: I.S.O. R 495
6. Complete interface available to Real Time Analyser and Punch Paper Tape for rapid collection of data, either acoustic or vibrations.

Approved by
Approuvee par ....

JUSTIFICATION: Cont'd ....

7. Digital channel control permits scanning rates of up to 1000 channels per second.

8. If more than eight channels of data required, additional units may be cascaded.

Supplier & Address:

Bruel & Kjaer Canada Limited,
90 Leacock Road,
Pointe Claire 700, Quebec. Telephone: (514) 695-8225

	PRICE LIST	DUTY FREE
1.	Channel Selector Type 5619	$ 2,010.00 approx.
2.	Microphones B & K	
	Condenser Microphones type 4133 at $232.00 each X 8	1,856.00
	Preamplifiers type 2619 at $308.00 each X 8	2,464.00
	Microphones Power Supply type 2807 at $574.00 each X 4	2,296.00
	Extension cables (30m) type A00029 at$108.00 each X 8	864.00
		$ 9,490.00

REQUEST FOR EXPENDITURE
DEMANDE DE DEFENSE D'ARGENT

MINING RESEARCH LABORATORY/ LABORATOIRE DE RECHERCHES MINIÈRES
Elliot Lake, Ontario

TITLE/ TITRE: Real Time Analyser, Level Recorders, Tape Punch, Amplifier, Calibrator with accessories.

DATE: November 20/72 PREPARED BY/PREPAREE PAR: M. Savich COST/ COÚT:

PROJECT/ PROJET: Laboratory equipment diagnostic and field analysis.

PROBLEM/ PROBLEME: Measurement of and calculations on all kinds of acoustic noise including impulsive noise and vibration amplitude value. Production control of frequency response and distortion of electro-acoustic devices. Acoustic measurements such as sound distribution and sound insulation. Evaluation of collected data on the field.

ALTERNATIVES CONSIDERED/AUTRE POSSIBILITÉS ENVISAGÉE: (No ALTERNATIVES)

1. Real Time Analyser Bruel & Kjaer Type 3347: Third octave bandwidth. Max. 38 channels, 12.5 Hz to 40k/Hz center frequencies. Digital output to Tape Punch. The logic control section controls the analog/digital conversion.
2. Level Recorders (B & K) Type 2307, Records DC Signals and RMS average or peak value of AC signals as function of time or frequency from 2 Hz to 200 k/Hz.
3. Tape Punch (B & K) Type 6301, Tape Punch is a 1" paper tape punch capable of punching 8 channels at up to 75 characters per second. It is used mainly for fast read-out from the Real Time 1/3 Octave Analyser type 3347.
4. Vibration Pic-Up Preamplifier (B & K) Type 2625 is used for measurement of acceleration, velocity and displacement with an accelerometer.
5. Accelerometer Calibrator (B & K) Type 4291 for calibration of accelerometers and other types of vibration transducers.

JUSTIFICATION: (PROJECT, ALTERNATIVES, Etc./ PROJET, POSSIBILITÉS, Etc.)

1. Analysis of non stationary, pass-by or impulsive type signals. Continuous speed analysis with maximum scanning rate of 2.15 milli/sec.
2. Analysis and Analog/Digital Conversion for Computer processing to complex relationships or statistical comparisons: Loudness calculators (ISO R.507) Averaging spectra, P.S.D. Machine Noise ISO R.495 etcetra.
3. Large visual display of data significance suited to signature analysis pattern recognition and monitoring.
4. Fast frequency response plots from pink noise excitation.
5. Can be expanded to 400 line Narrow Band Analyser covering the range DC to 20 k/Hz with additional units.

Approved by
Approuvée par..........................

Supplier & Address:

Bruel & Kjaer Canada Limited,
90 Leacock Road,
Pointe Claire, Quebec Telephone: (514) 695-8225

	PRICE LIST	DUTY FREE
1.	Real Time Analyser (B & K) Type 3347	$ 14,883.00
2.	Level Recorder (B & K) Type 2307	2,522.00
	(new type)	(2,522.00 + 20%)
3.	Tape Punch (B & K) Type 6301	3,653.00
4.	Vibration Pick-Up Preamplifier (B & K) Type 2625	435.00
5.	Accelerometer Calibrator (B & K) Type 4291	636.00
6.	Accessories:	
	Mini Cable (250° C.)Type A00038	9.00
	Mini Cable (100° C.) Type A00037	6.00
	Plug Type JP0028	10.00
		$ 22,154.00
		+ 2,000.00
		$ 24,154.00

REQUEST FOR EXPENDITURE
DEMANDE DE DEFENSE D'ARGENT

Mining Research Laboratory / Laboratoire de recherches minières
Elliot Lake, Ontario.

TITLE/TITRE: Sound and Vibration Set, Vibration Sets and Tape Recorder

DATE: November 20/72 PREPARED BY/PREPARÉE PAR M. Savich Cost/Coût: ____

PROJECT/PROJET: Field Measurement; Noise and Vibration

PROBLEM/PROBLÈME: Noise and Vibration measurements for health protection and for quality inspection and development in industry can be measured or recorded. Noise levels as well as vibration frequency ranges can be found in the laboratory.

ALTERNATIVES CONSIDERED/AUTRES POSSIBILITÉS ENVISAGÉES: NO ALTERNATIVES

1. Sound and Vibration Set (B & K) Type 3507
   (new instrument; Octave and Third Octave Filter
2. The Accelerometer set (B & K) Type 8304S
3. Accelerometer, miniature set (B & K) Type 8307
4. Tape Recorder (B & K) Type 7004.

(see appendix)

JUSTIFICATION:

1. Sound and Vibration set Type 3507 features:
   - a) Complies with all existing standards for impulse and precision sound level meters.
   - b) Impulse measurement with maximum RMS hold.
   - c) Frequency range 20 Hz to 70 k/Hz.
   - d) A. B. C. D. Linear frequency response.
   - e) Dynamic range down to 15 db (A).
   - f) Third octave and octave filter set available.
   - g) Performs as a vibration meter with an accelerometer.
   - h) Battery operated (replacements at any drug store).
   - i) Measure peak value of impacts down to 20 micro/seconds and holds level.
   - j) Can be supplied to narrow band tuneable filter for vibration (B & K) Type 5613
     (see appendix)

Approved by
Approuvée par ....

ALTERNATIVES CONSIDERED

MAIN APPLICATIONS

1. Sound and Vibration set (B & K) Type 3507.

   a) Impulse Precision Sound Level Meter Type 2209

   - Noise investigations, especially where impulse or transient sound is predominant e.g. noise from sheet metal workshop, punch and press workshops, passing vehicles etcetra.
   - Noise and Vibration measurements for health protection.
   - Acoustic measurements also where very high or very low frequencies are to be measured.
   - Audiometer calibration.

   b) Third octave and octave filter set (B & K) Type 1613 and 1616

   - Machinery noise investigations.
   - Loudness evaluation.
   - Calibration of Audiometers.
   -
   - Noise checks according to legal requirements.

2. The Accelerometer set (B & K) Type 8304S
   Uses: Vibration measurements at changing temperatures and under influence of temperature transients.

3. Accelerometer, minature, set (B & K) Type 8307
   Uses: Vibration measurements on the human body.

4. Tape Recorder (B & K) Type 7004

   - Field recording and storage of acoustic and vibration data.
   - Frequency transformation

JUSTIFICATION:

2. The Accelerometer set Type 8304S features;

   a) High sensitivity stability over wide temperature range.

   b) Low sensitivity to temperature transients.

   c) Low sensitivity to base strain.

   d) All important data individually calibrated and supplied.

3. Accelerometer, miniature, set Type 8307

   a) High level and high frequency measurements

   b) Ideal for measurements on the human body.

4. Tape Recorders Type 7003 and 7004

   a) 7003 FM Recording DC to 10 k/Hz 4 channels
   7004 Direct recording 20 Hz to 50 k/Hz 2 channels

   b) Extremely low flutter

   c) May be used under rough environmental conditions in the field due to unique opposing fly wheel feature.*

   d) Battery powered with re-changeable or replaceable batteries.

   e) Low weight - 15.5 lbs.

*(One very important feature of this instrument will be the use of two opposing fly wheels used in the drive system to maintain constant speed even when subjected to heavy vibration such as a hauler etc.)

Supplier & Address:

Bruel & Kjaer Canada Limited,
90 Leacock Road,
Pointe Claire 700, Quebec. Telephone: (514) 695-8225

	PRICE LIST	DUTY FREE
1.	Sound and Vibration set B & K Type 3507 (new instrument; Third Octave & Octave Filter Set) consisting of the following instruments;-	$ 2,974.00
	Type 2209 Impulse precision sound level meter c/w accessories	
	Type 1613 Octave Filter Set	
	Type 4220 Pistonphone	
	Type 4332 (4312) Accelerometer set	
	Type 4133 Microphone ½"	
	Type UA0055 Random Incidence Corrector	
	Type UA0082 Windscreen	
	Type UA0051 Nose Cone 1"	
	Type UA0052 Nose Cone ½"	
	Type ZR0020 Integrator	
	Type UA0028 Adaptor for tripod	
	Type UA0027 Extension cable	
	Type KE0055 Carrying case	
2.	Standard accelerometer B & K Type 8304S	354.00
3.	Accelerometer, miniature, set Type 8307	215.00
4.	Vibration Calibrator Type 4291	636.00
5.	Tape Recorders Type 7003 and 7004 (not yet price)	6,000.00
		$ 10,179.00

REQUEST FOR EXPENDITURE

DEMANDE DE DEFENSE D'ARGENT

Mining Research Laboratory/ Laboratoire de recherches minières
Elliot Lake, Ontario.

TITLE/TITRE: Aural Microphone and Accessories

DATE: November 21/72 PREPARED BY/PREPAREE PAR: M. Savich COST/COUT: $878.00

PROJECT/PROJET:-

PROBLEM/PROBLEME: A small microphone located on the base of the cochlea provides information on the acoustical signal entering the ear canal and can be used to examine an individual's exposure to noise when coupled to a portable tape recorder.

ALTERNATIVES CONSIDERED/AUTRE POSSIBILITÉS ENVISAGÉES: (NO ALTERNATIVES)

1. Microphone 1/4" Type 4136
2. Flexible Adaptor for side mounting of 1/4" and 1/2" microphone cartidges (for 1/2" preamplifier)
3. Preamplifier 1/2" Type 2619
4. Probe microphone kit type UA0040

JUSTIFICATION: (PROJECT, ALTERNATIVES, etc./PROJET, POSSIBILITÉS, etc)

1. A small microphone can be used in a variety of applications such as measurements in the human ear and for the measurement of high sound pressure levels.
2. The adaptor set UA0122 permits flush mounting of the microphone in ducts for measurement and analysis of turbulence.

Approved by
Approuvée par ....

Supplier & Address:

Bruel & Kjaer Canada Limited,
90 Leacock Road,
Pointe Claire 700, Quebec. Telephone: (514) 695-8225

PRICE LIST	DUTY FREE
1. Microphone 1/4" Type 4136	$ 232.00
2. Flexible adaptor for UA0122	92.00
3. Preamplifier 1/2" Type 2619	308.00
4. Probe microphone kit Type UA0040	246.00
	$ 878.00

REQUEST FOR EXPENDITURE
DEMANDE DE DEFENSE D'ARGENT

Mining Research Laboratory / Laboratoire de recherches minieres
Elliot Lake, Ontario.

TITLE/TITRE: Noise Exposure Dosimeter with accessories

DATE: ______ PREPARED BY/PREPARÉE PAR: M. Savich COST/COUT: ______

PROJECT/PROJET: Mine Noise Survey

PROBLEM/PROBLÈME: To determine the noise levels to which underground employees are exposed, to evaluate noise survey techniques and equipment and compare noise exposures using two instruments; sound level meter and noise exposure dosimeters.

ALTERNATIVES CONSIDERED/AUTRES POSSIBILITÉS ENVISAGÉES:

1. Bausch & Lomb Optical Co. Ltd., 05-81-59 Dosimeter with holder
   05-81-57 Calibrator
   05-81-58 Carrying case
2. Bendix Inc., 1150 Monitor, 1100 Readout.
3. Columbia Research Laboratories Inc., SPL-104, AB, SPC-10 Calibrator
4. Dupont, Dosimeter and Readout.
5. General Radio, G.R. 1944 Noise Exposure Monitor, G.R., 1944 Noise Exposure Indic.
6. Magnatronics, Monitor and Readout.
7. Quest Film Productions Ltd., M-6 Dosimeter, CA-10 Calibrator.
8. 3M Company, NMI Dosimeter, NCCI Charger/Calibrator.
9. Willson Products Division, IN Monitor, Readout. (see Appendix)

JUSTIFICATION: (PROJECT, ALTERNATIVES, etc./ PROJET, POSSIBILITÉS, etc.)

The General Radio preferred over all equivalents (1,2,3,4,6,7,8,&9 above) because of:

1) Instrumentation will not become obsolete when the law changes.
2) The windscreen has all monitors.
3) Small shirt-pocket size, lightweight, 7 1/2 ozs.
4) Long battery life - 300 hrs.
5) The calibrator checks complete system including microphone.
6) Readout available only to authorised personnel.
7) The first, second, third and fourth alternatives give an advantage over all types of instruments.

Approved by
Approuvée par ....

Supplier & Address:

General Radio Canada Limited,
307 Evans Avenue, Toronto 530,
Tel (416) 252-3395

ALTERNATIVES CONSIDERED

Competitor	Instrument	Weight	Price $	Note
1 Bausch & Lomb Optical Comp. Ltd.	05-81-59 Dosimeter with holder 05-81-57 Calibrator 05-81-58 Carrying Case		480.00 245.00 17.00 742.00	Products: Columbia Research Laboratories Inc.
2 Bendix Inc.	1150 Monitor 1100 Readout		250.00 650.00 900.00	No reputation or service
3 Columbia Research Laboratories, Inc.	SPL-104 AB SPC- 10 Calib.	1702	455.00 125.00 580.00	No reputation
4 Du Pont	Dosimeter Readout		495.00 250.00 745.00	No calibration. Readout destroys explosure info.
5 General Radio	GR 1944 Noise -Exposure Monitor GR 1944 Noise Exposure Indicator	7½ oz	350.00 495.00 845.00	85 dBA provision is built-in
6 Magnatronics	Monitor Readout		495.00 495.00 990.00	Only Film Production

Competitor	Instrument	Weight	Price $	Note
7 Quest Film Productions Ltd.	M-6 CA-10 Calib.	2502	395.00 230.00 625.00	Large Exposed Readout
8 3 M Company	NM1 NCCI Charger/ Calib.		495.00 495.00 990.00	Only Film Production
9 Willson Products Division	IN-14 Readout	1902	295.00 198.00 493.00	No acoustic calibration, must be returned to the factory for service

10. CONCLUSION

The chances for future preservation of the mine environment are good. This practice will avoid surprises in the form of extra costs. Planning in the Canadian Mining Industry in favour of man and environment is for many a wish today but will be a necessity tomorrow.

The analysis showed that unwanted sound is not new to the Canadian mining industry. Until now, insufficient measures have been taken to control noise and vibration.

Future organized and extensive work will be as follows:

1. Organizing a cooperative effort among government, noise specialists, mines and mining machinery manufacturers to accumulate the noise and vibration data required in industrial hygienists (Safety departments in mines) in their evaluation of the man/noise and man/vibration effects in the mining environment.
2. ·Creating information on mining machine noise for use by regulatory bodies, consumers, and information ways.
3. Investigating a means to mining machinery noise sources in a uniform, usable and reliable manner.
4. Elaborating a manual for mines where great attention will be concentrated on the basic noise measurement standards:
    - noise measurement at operator station,
    - noise measurement according to standards,
    - mining job site noise measurement, and
    - cumulative operator noise exposure measurement during shift with standardized reporting methods.

The tasks of the mining machinery manufacturers are:

1. Evaluating the noise to each machine according to the Standards.
2. Evaluating the many noise sources peculiar to each machine.
3. Developing operator enclosures for future products.
4. Developing quieter components and systems for quieter machines for current products.

The report represented the situation about noise and vibration in Canadian mines.

Great possibilities are shown which are available to the Canadian mining industry in the struggle for noise and vibration reduction.

Proposals are given for the improvement of the work in the field of noise and vibration in Canadian mines and the first steps already are undertaken in this direction.

11. ACKNOWLEDGEMENTS

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Detailed instructions were given by T. S. Cochrane, Manager, Mining Research Centre.

G. Zahary, Manager, Elliot Lake Laboratory and G. Knight, Research Scientist, sincerely participated and gave advice during the elaboration of the project.

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APPENDIX

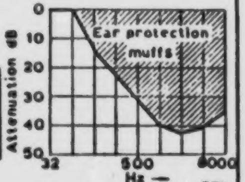
MINING RESEARCH LABORATORY	NOISE MEASUREMENT IN OCTAVE BANDS	ELLIOT LAKE
Date of measurement 23.10 70	Breakers:TEX 30 and TEX 30S-ATLAS COPCO Roadbreaking in concrete	Montreal Page 1 Sign.

No	dB(A)	dB(C)	dB(Lin)	N	N(P)	Note
1	109		112	109	81	Non silenced ●——
2	101		103	101	68	Silenced O- - - -
3	95			103	81	" at the operators ear •——
4	84			94	66	" at 7m distance •- - - - -

Acoustic environment Free field

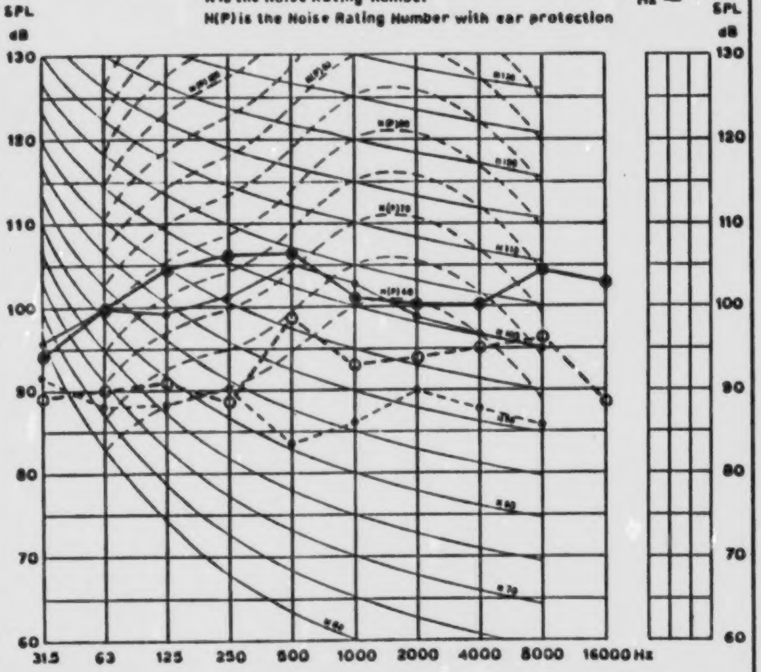
Microphon distance 1 metres

Technical data	Tool shank	Piston diamet mm.	Piston stroke mm.	Blows per min	Total lenght mm.	Weight kg.	Air consum at 6kp/cm² m³/min
TEX30	1¼"x6"	52	155	1150	720	28	16
TEX30S	1¼"x6"	52	155	1150	720	29.5	1.6



N is the Noise Rating Number

N(P) is the Noise Rating Number with ear protection



Prepared by: M.U.SAVICH

From data by: Atlas Copco

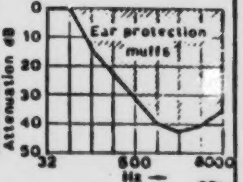
MINING RESEARCH LABORATORY	NOISE MEASUREMENT IN OCTAVE BANDS	ELLIOT LAKE
Date of measurement 23.10.70	Breakers: TEX 30 and TEX 30S-ATLAS COPCO Roadbreaking in asphalt	Montreal Page 2 Sign.

No	dB(A)	dB(C)	dB(Lin)	N	N(P)	Note
1	106		110	107	80	Non silenced ●——
2	99		101	99	68	Silenced O- - - -
3	93			103	81	" at the operators ear •——
4	82			92	67	" at 7m distance •- - - - -

Acoustic environment Free field

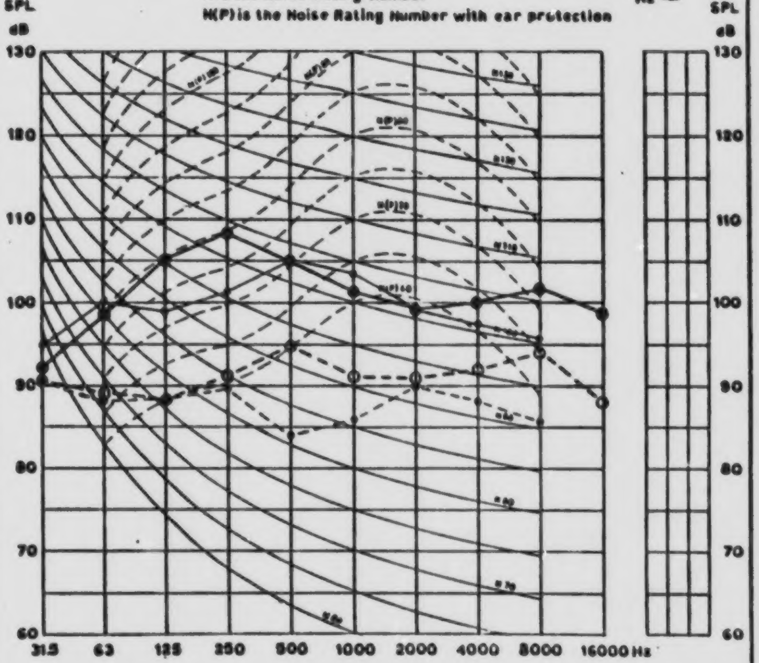
Microphon distance 1 metres

Technical data	Tool shank	Piston diamet. mm.	Piston stroke mm.	Blows per min.	Total lenght mm.	Weight kg.	Air consump. at 6kp/cm² m³/min
TEX30	1¼"X6"	52	155	1150	720	28	1.6
TEX30S	1¼"X6"	52	155	1150	720	29.5	1.6



N is the Noise Rating Number

N(P) is the Noise Rating Number with ear protection



Prepared by: M.U.SAVICH

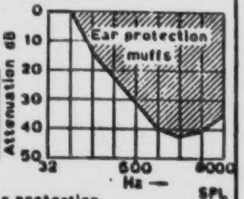
From data by: Atlas Copco

MINING RESEARCH LABORATORY	NOISE MEASUREMENT IN OCTAVE BANDS	ELLIOT LAKE
Date of measurement 27.8.71	Breakers: TEX40 and TEX40S - ATLAS COPCO Roadbreaking in concrete	Montreal Page 3 Sign.

No	dB(A)	dB(C)	dB(LIN)	N	N(P)	Note
1	107		112	105	77	Non silenced ●——
2	104		105	101	65	Silenced ○- - -
3	87					" at 7m distance
4						

Acoustic environment Free field

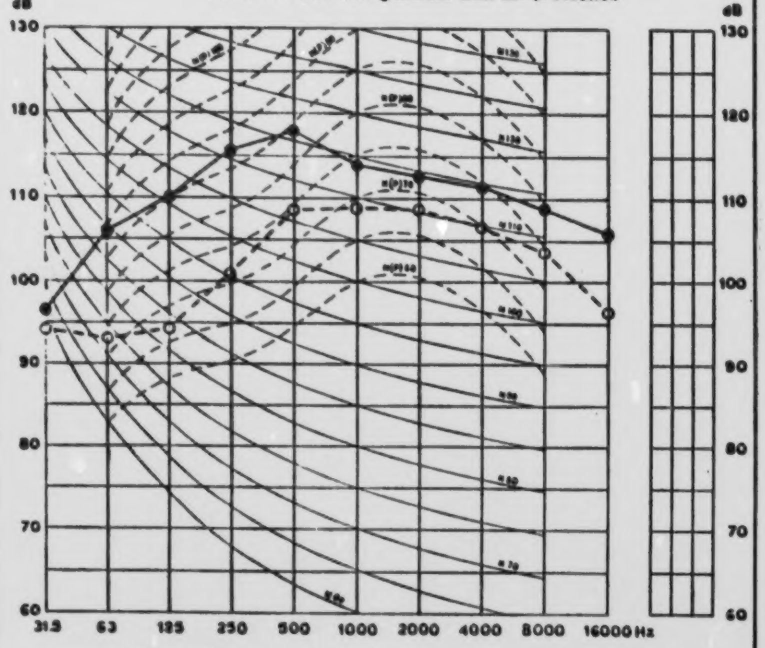
Microphon distance 1 metres



Technical data	Tool shank	Piston diamet mm	Piston stroke mm.	Blows per min.	Total lenght mm.	Weight kg.	Air consum. at 6 kp/cm² m³/min
TEX40	1¼"x6"	58	165	1150	740	36	2.0
TEX40S	1¼"x6"	58	165	1150	740	36	2.0

N is the Noise Rating Number

N(P) is the Noise Rating Number with ear protection



Prepared by: M.U.SAVICH

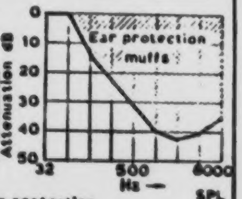
From data by: Atlas Copco

MINING RESEARCH LABORATORY	NOISE MEASUREMENT IN OCTAVE BANDS	ELLIOT LAKE
Date of measurement 27.8.71	Breakers: TEX50 and TEX50S - ATLAS COPCO Roadbreaking in concrete	Montreal Page 4 Sign.

No.	dB(A)	dB(C)	dB(LIN)	N	N(P)	Note
1	108		112	106	78	Non silenced ●——
2	102		104	102	68	Silenced ○- - -
3	85					" at 7m distance
4						

Acoustic environment Free field

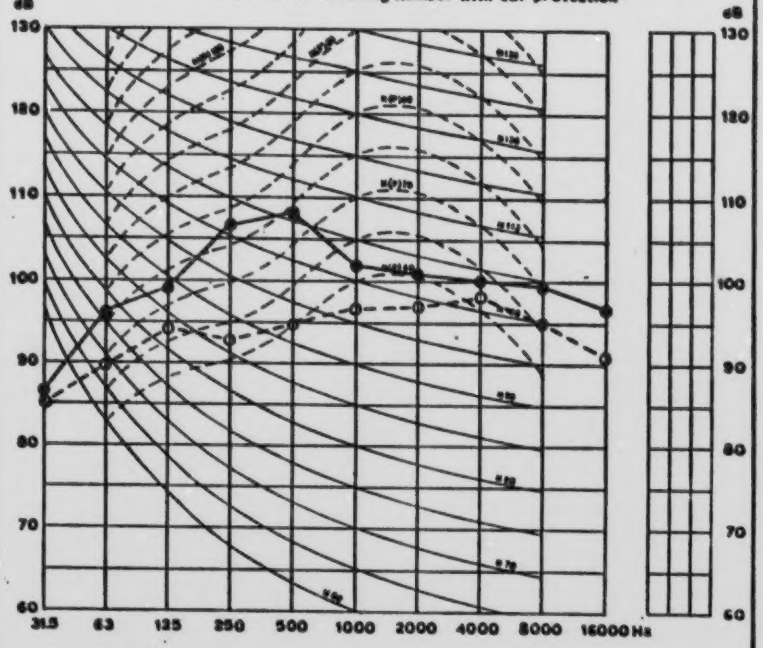
Microphon distance 1 metres



Technical data	Tool shank	Piston diamet mm.	Piston stroke mm.	Blows per min.	Total lenght mm	Weight kg.	Air consum. at 6kp/cm² m³/min
TEX50	1¼"x6"	58	165	1170	730	38.5	2.1
TEX50S	1¼"x6"	58	165	1170	730	38.5	2.1

N is the Noise Rating Number

N(P) is the Noise Rating Number with ear protection



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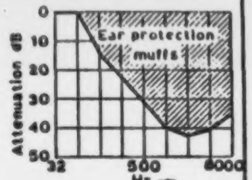
From data by: Atlas Copco

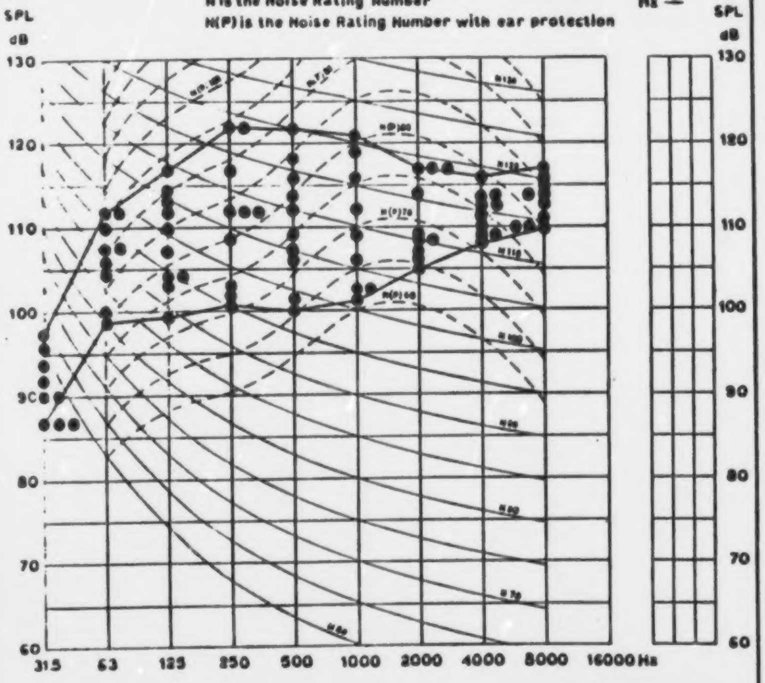
MINING RESEARCH LABORATORY	NOISE MEASUREMENT IN OCTAVE BANDS	ELLIOT LAKE
Date of measurement 1968	Rock drills	Ontario Metal Mines Page 5 Sign.

No	dB(A)	dB(C)	dB(LIN)	N	N(P)	Note
1	[illegible]			122	86	Maximum
2	[illegible]			114	81	Minimum
3						
4						

Acoustic environment Reverberant field
Microphon distance Operator



N is the Noise Rating Number
N(P) is the Noise Rating Number with ear protection



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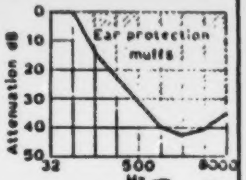
From data by: MAPAO

MINING RESEARCH LABORATORY	NOISE MEASUREMENT IN OCTAVE BANDS	ELLIOT LAKE
Date of measurement 1968	Stopers	Ontario Metal Mines Page Sign 6

No	dB(A)	dB(C)	dB(LIN)	N	N(P)	Note
1	116			117	82	Maximum
2	1115			113	79	Minimum
3						
4						

Acoustic environment Reverberant field
Microphon distance Operator



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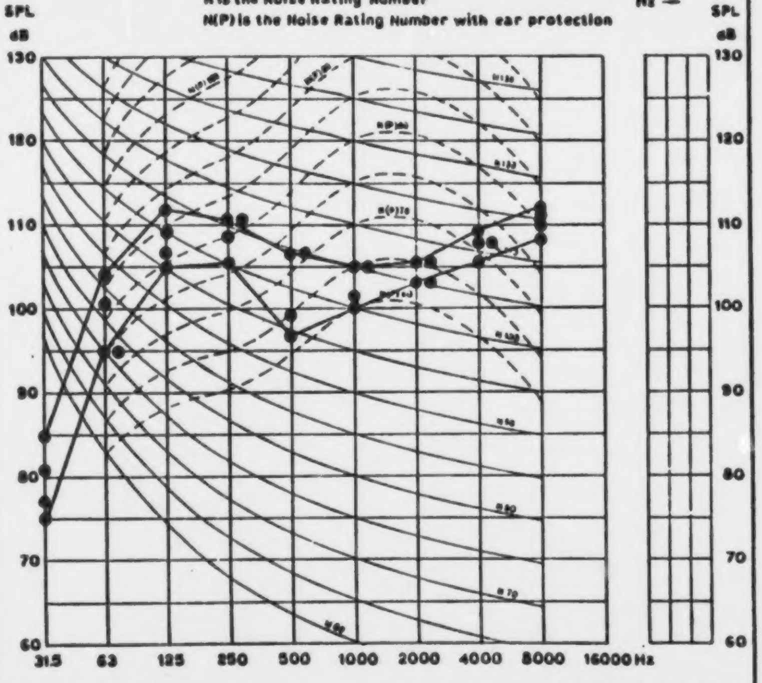
N(P) is the Noise Rating Number with ear protection



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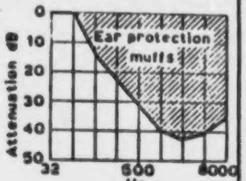
From data by: MAPAO

MINING RESEARCH LABORATORY	NOISE MEASUREMENT IN OCTAVE BANDS	ELLIOT LAKE
Date of measurement 1968	Diamond drills	Ontario Metal Mines Page 7 Sign.

No	dB(A)	dB(C)	dB(LIN)	N	N(P)	Note
1	109	—		106	76	Maximum
2	93.5	—		93	-	Minimum
3						
4						

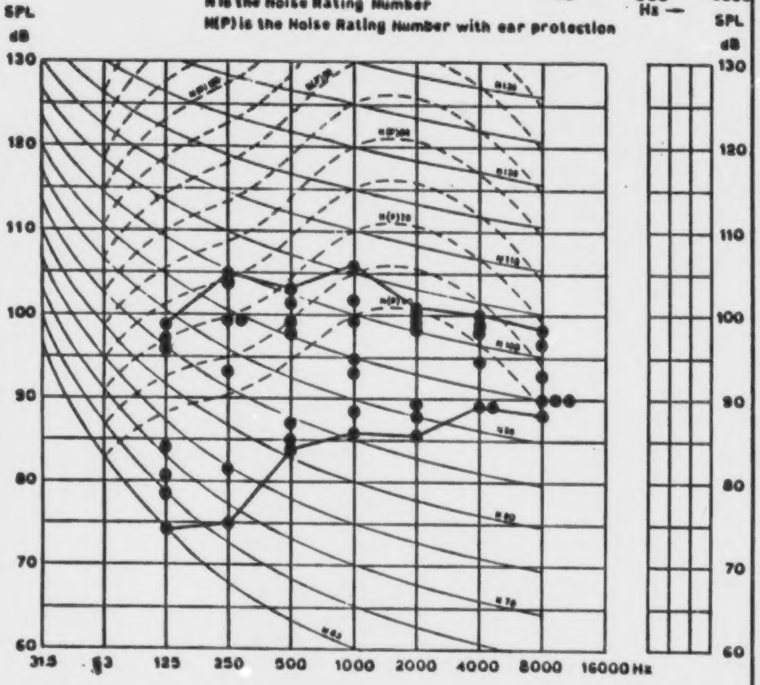
Acoustic environment Free and reverberant fields

Microphon distance Operator



N is the Noise Rating Number

N(P) is the Noise Rating Number with ear protection



Prepared by: M.U.SAVICH

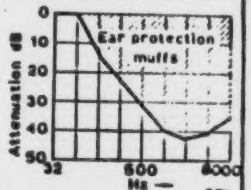
From data by: MAPAO

MINING RESEARCH LABORATORY	NOISE MEASUREMENT IN OCTAVE BANDS	ELLIOT LAKE
Date of measurement 1968	Mucking machines	Ontario Metal Mines Page 8 Sign.

No.	dB(A)	dB(C)	dB(LIN)	N	N(P)	Note
1	111			114	86	Maximum
2	110			112	77	Minimum
3						
4						

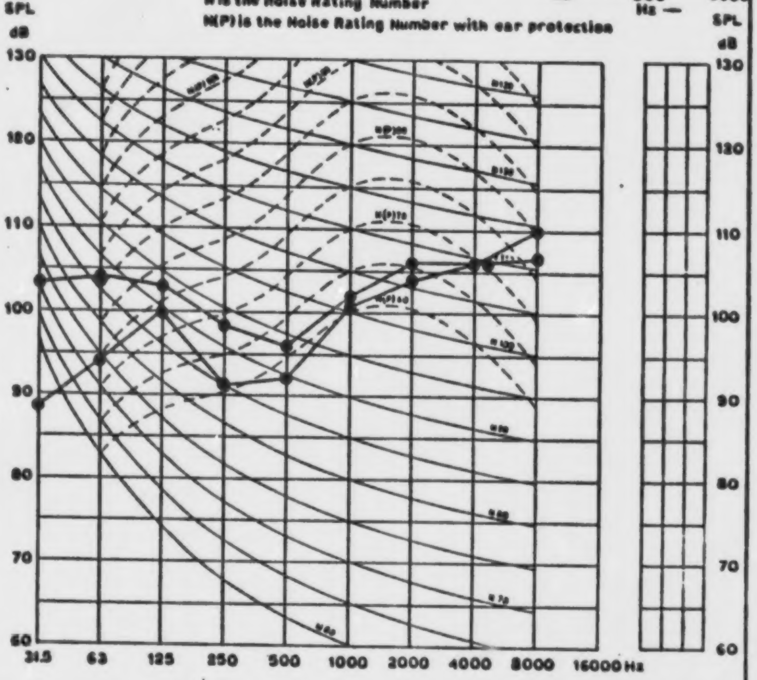
Acoustic environment Reverberant field

Microphon distance Operator



N is the Noise Rating Number

N(P) is the Noise Rating Number with ear protection



Prepared by: M.U.SAVICH

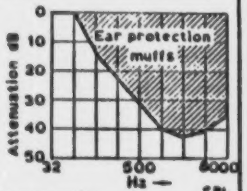
From data by: MAPAO

MINING RESEARCH LABORATORY	NOISE MEASUREMENT IN OCTAVE BANDS	ELLIOT LAKE
Date of measurement 1968	50 H.P. Slusher	Ontario Metal Mines Page 9 Sign.

No	dB(A)	dB(C)	dB(LIN)	N	N(P)	Note
1	104			105	71	
2						
3						
4						

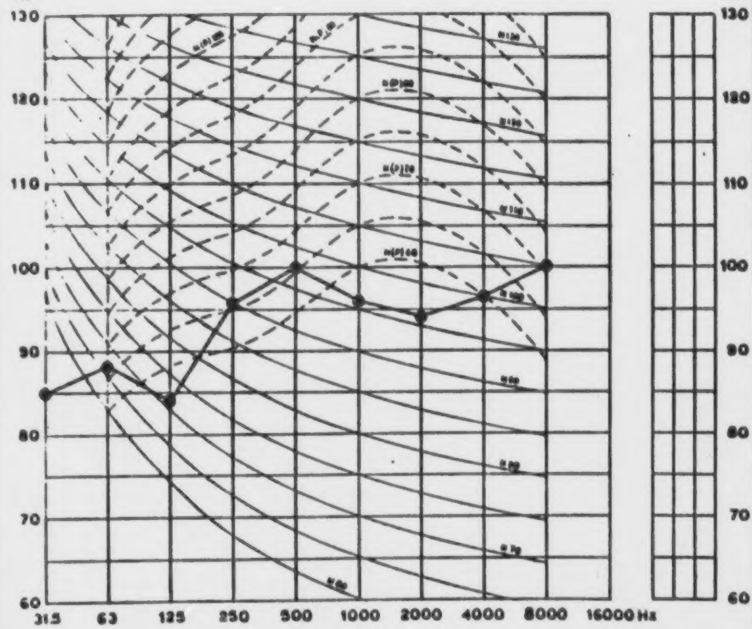
Acoustic environment Reverberant field

Microphon distance Operator



N is the Noise Rating Number

N(P) is the Noise Rating Number with ear protection



Prepared by: M.U.SAVICH

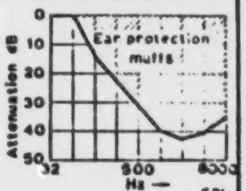
From data by: MAPAO

MINING RESEARCH LABORATORY	NOISE MEASUREMENT IN OCTAVE BANDS	ELLIOT LAKE
Date of measurement 1968	Fans	Ontario Metal Mines Page 10 Sign.

No	dB(A)	dB(C)	dB(LIN)	N	N(P)	Note
1	104			100	67	Maximum
2	79			75	-	Minimum
3						
4						

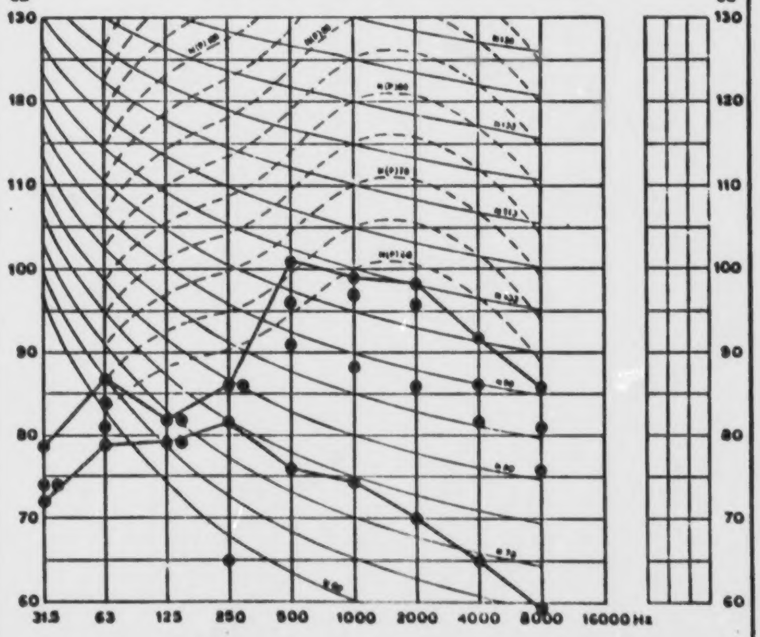
Acoustic environment Reverberant field

Microphon distance Operator



N is the Noise Rating Number

N(P) is the Noise Rating Number with ear protection



Prepared by: M.U.SAVICH

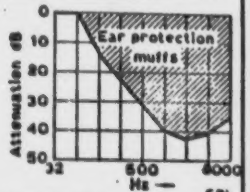
From data by: MAPAO

MINING RESEARCH LABORATORY	NOISE MEASUREMENT IN OCTAVE BANDS	ELLIOT LAKE
Date of measurement 1968	Diesel truck	Ontario Metal Mines Page 11 Sign.

No	dB(A)	dB(C)	dB(LIN)	N	N(P)	Note
1	102			100	70	Maximum
2	91			90	63	Minimum
3						
4						

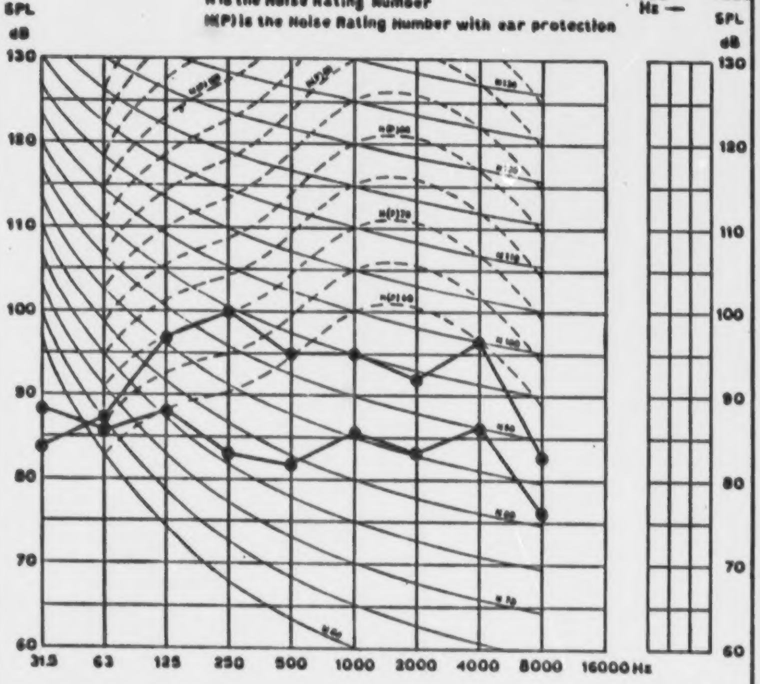
Acoustic environment Free field

Microphon distance Operator



N is the Noise Rating Number

N(P) is the Noise Rating Number with ear protection



Prepared by: M.U.SAVICH

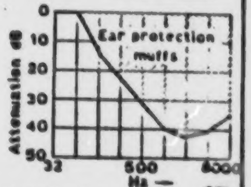
From data by: MAPAO

MINING RESEARCH LABORATORY	NOISE MEASUREMENT IN OCTAVE BANDS	ELLIOT LAKE
Date of measurement 1968	Primary crushers	Ontario Metal Mines Page 12 Sign.

No.	dB(A)	dB(C)	dB(LIN)	N	N(P)	Note
1	99			95	82	Maximum
2	82			78	-	Minimum
3						
4						

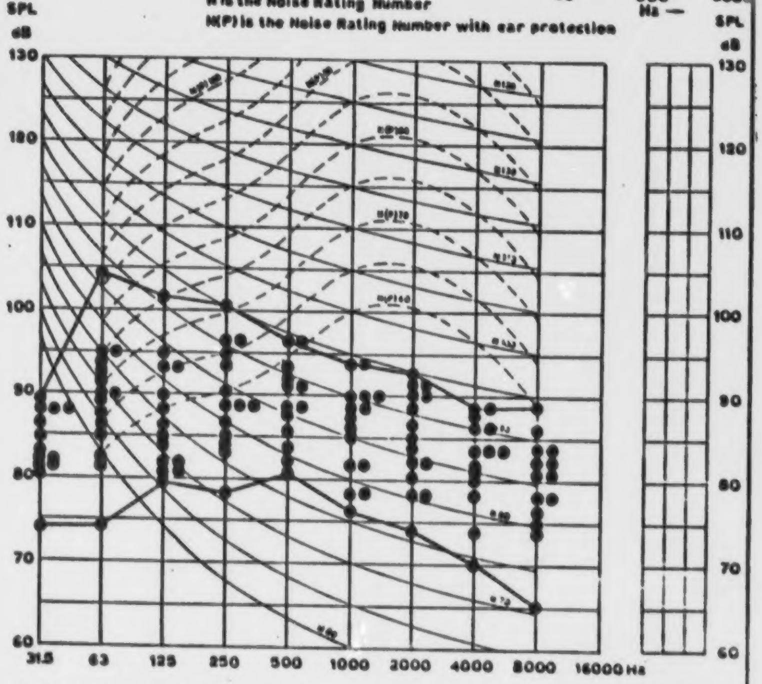
Acoustic environment Reverberant field

Microphon distance Operator



N is the Noise Rating Number

N(P) is the Noise Rating Number with ear protection



Prepared by: M.U.SAVICH

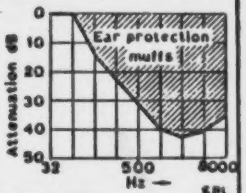
From data by: MAPAO

MINING RESEARCH LABORATORY	NOISE MEASUREMENT IN OCTAVE-BANDS	ELLIOT LAKE
Date of measurement 1968	Cone crushers	Ontario Metal Mines
		Page 13 Sign.

No	dB(A)	dB(C)	dB(Lin)	N	N(P)	Note
1	[illegible]			96	93	Maximum
2	[illegible]			82	-	Minimum
3						
4						

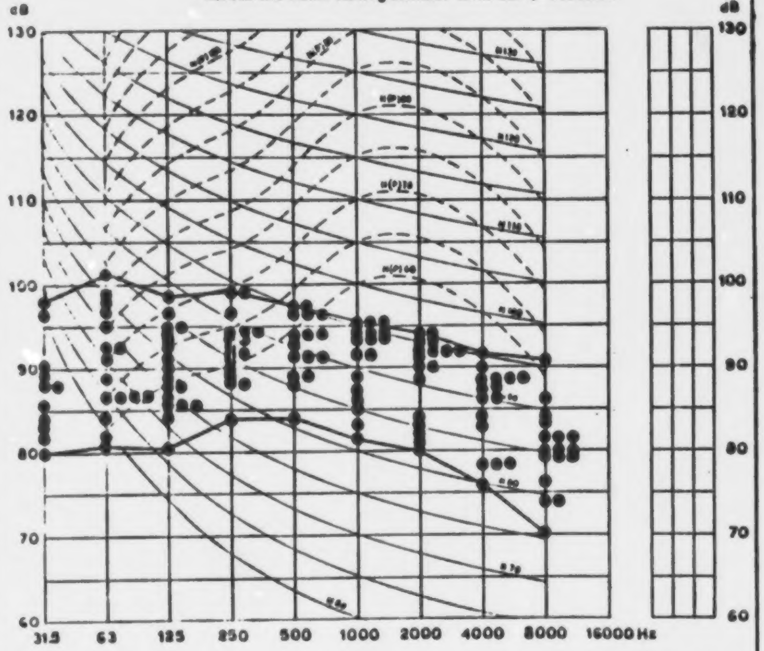
Acoustic environment Reverberant field

Microphon distance Operator



N is the Noise Rating Number

N(P) is the Noise Rating Number with ear protection



Prepared by: M.U.SAVICH

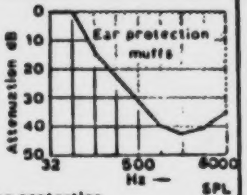
From data by: MAPAO

MINING RESEARCH LABORATORY	NOISE MEASUREMENT IN OCTAVE BANDS	ELLIOT LAKE
Date of measurement 1968	Rools crushers	Ontario Metal Mines
		Page 14 S.gn.

No	dB(A)	dB(C)	dB(Lin)	N	N(P)	Note
1	97			93	78	Maximum
2	90			86	71	Minimum
3						
4						

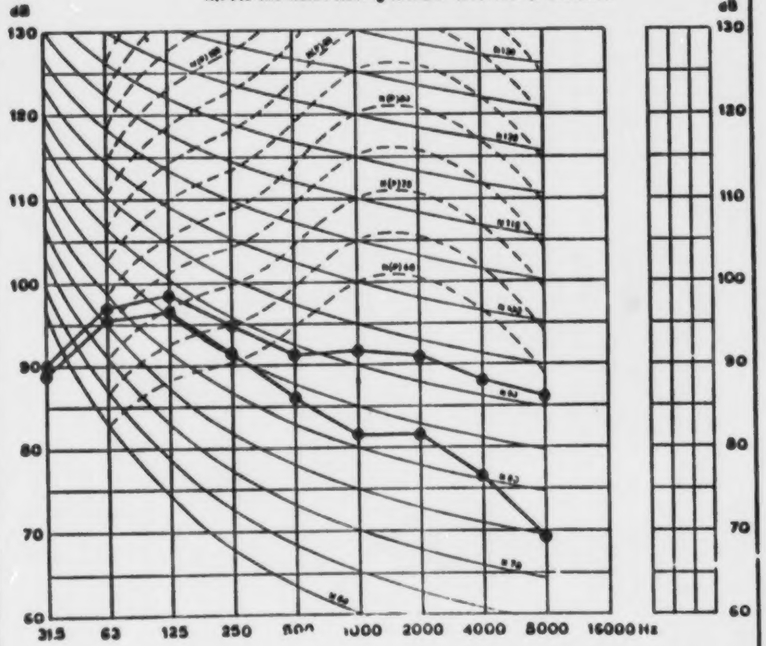
Acoustic environment Reverberant field

Microphon distance Operator



N is the Noise Rating Number

N(P) is the Noise Rating Number with ear protection



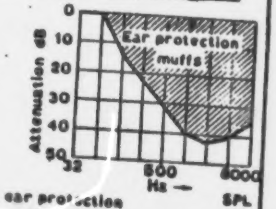
Prepared by: M.U.SAVICH

From data by: MAPAO

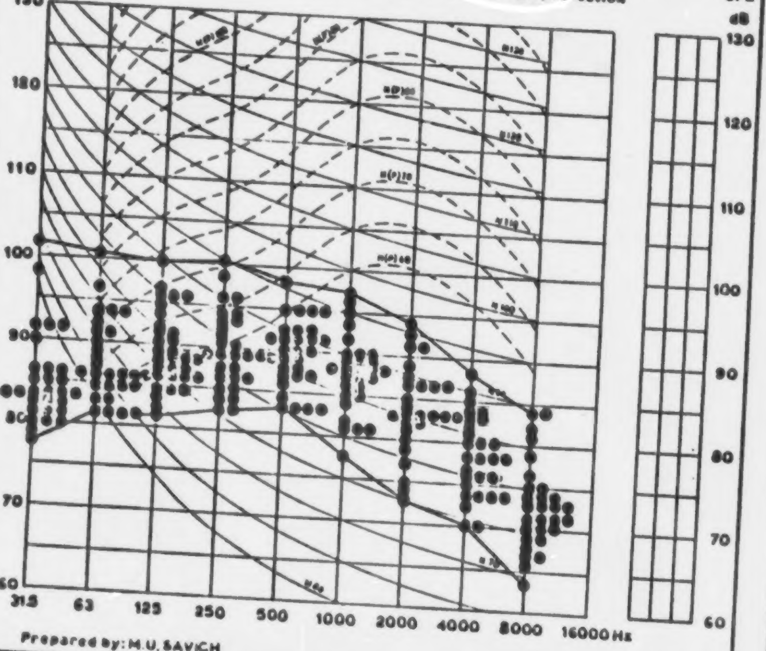
MINING RESEARCH LABORATORY	NOISE MEASUREMENT IN OCTAVE- BANDS Grinding unitis: Ball, rod, tube, pebble mills	ELLIOT LAKE
Date of measurement 1968		Ontario Metal Mines Page 15 Sign.

No	dB(A)	dB(C)	dB(LIN)	N	N(P)	Note
1	101			97.5	92	Maximum
2	84			80	-	Minimum
3						
4						

Acoustic environment Reverberant field
Microphon distance Operator



N is the Noise Rating Number
N(P) is the Noise Rating Number with ear protection



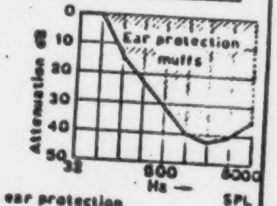
Prepared by: M.U. SAVICH

From data by: MAPAO

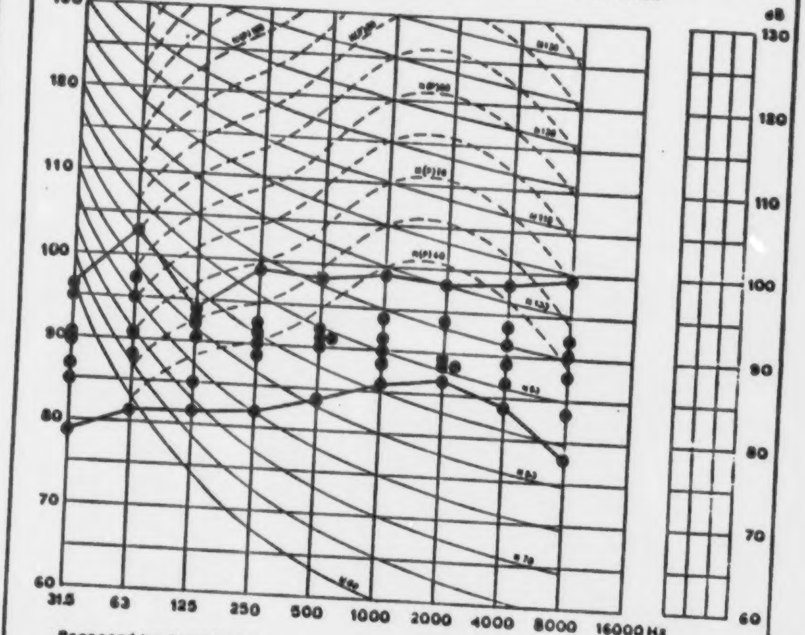
MINING RESEARCH LABORATORY	NOISE MEASUREMENT IN OCTAVE BANDS Vibrating screen	ELLIOT LAKE
Date of measurement 1968		Ontario Metal Mines Page 16 Sign.

No.	dB(A)	dB(C)	dB(LIN)	N	N(P)	Note
1	105			104	85	Maximum
2	93			88	-	Minimum
3						
4						

Acoustic environment Reverberant field
Microphon distance Operator



N is the Noise Rating Number
N(P) is the Noise Rating Number with ear protection



Prepared by: M.U. SAVICH

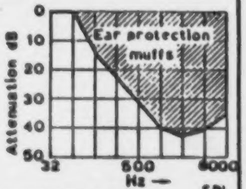
From data by: MAPAO

MINING RESEARCH LABORATORY	NOISE MEASUREMENT IN OCTAVE BANDS	ELLIOT LAKE
Date of measurement 1968	Vacuum pumps	Ontario Metal Mines Page 17 Sign.

No	dB(A)	dB(C)	dB(LIN)	N	N(P)	Note
1	94			88	65	Maximum
2	91			90	62	Minimum
3						
4						

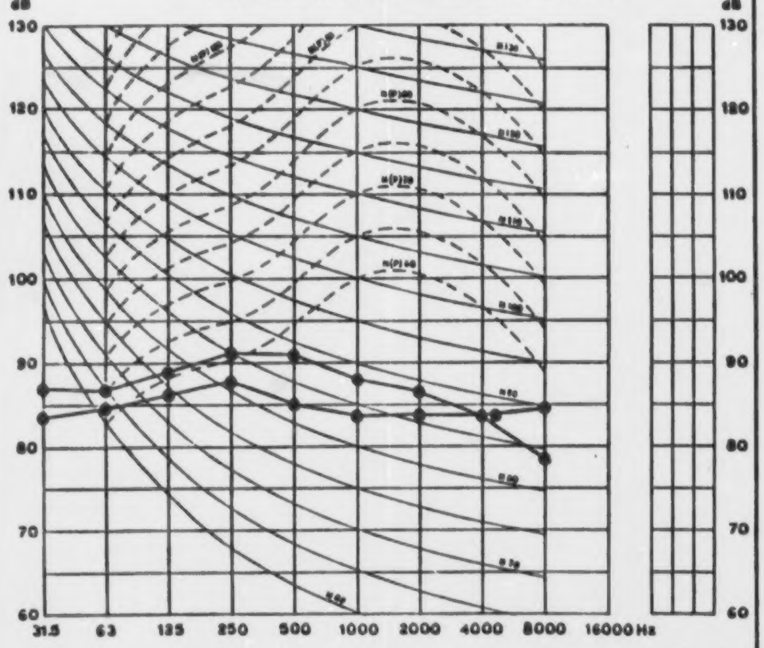
Acoustic environment Reverberant field

Microphon distance Operator



N is the Noise Rating Number

N(P) is the Noise Rating Number with ear protection



Prepared by: M.U.SAVICH

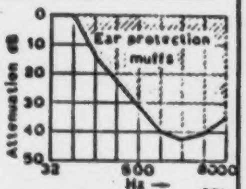
From data by: MAPAO

MINING RESEARCH LABORATORY	NOISE MEASUREMENT IN OCTAVE BANDS	ELLIOT LAKE
Date of measurement 1968	Compressors	Ontario Metal Mines Page 18 Sign.

No	dB(A)	dB(C)	dB(LIN)	N	N(P)	Note
1	95.9			93	88	Maximum
2	71.6			65	-	Minimum
3						
4						

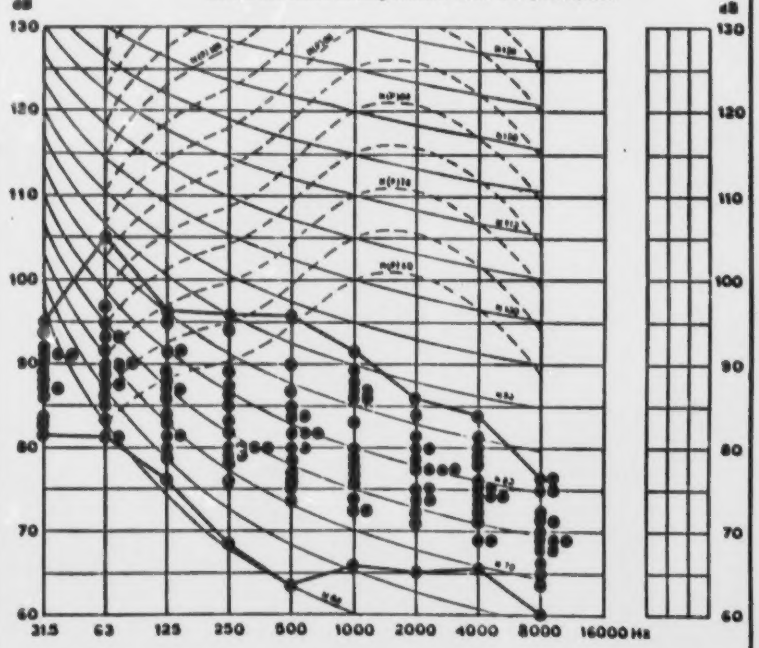
Acoustic environment Reverberant field

Microphon distance Operator



N is the Noise Rating Number

N(P) is the Noise Rating Number with ear protection



Prepared by: M.U.SAVICH

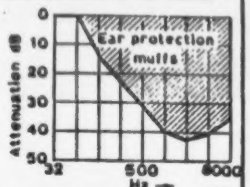
From data by: MAPAO

MINING RESEARCH LABORATORY	NOISE MEASUREMENT IN OCTAVE BANDS	ELLIOT LAKE
Date of measurement 1968	Hoists	Ontario Metal Mines Page 19 Sign.

No.	dB(A)	dB(C)	dB(LIN)	N	N(P)	Note
1	83			84	72	Maximum
2	68			64	–	Minimum
3						
4						

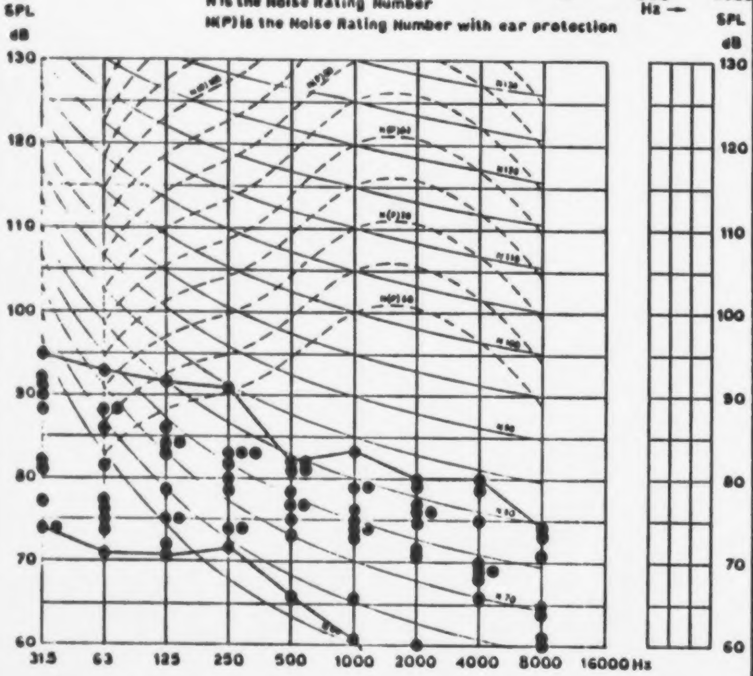
Acoustic environment Reverberant field

Microphon distance Operator



N is the Noise Rating Number

N(P) is the Noise Rating Number with ear protection



Prepared by: M.U.SAVICH

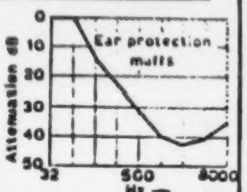
From data by: MAPAO

MINING RESEARCH LABORATORY	NOISE MEASUREMENT IN OCTAVE BANDS	ELLIOT LAKE
Date of measurement 1968	Pellet plants	Ontario Metal Mines Page 20 Sign.

No.	dB(A)	dB(C)	dB(LIN)	N	N(P)	Note
1	93.5			96	80	Maximum
2	85.4			83	62	Minimum
3						
4						

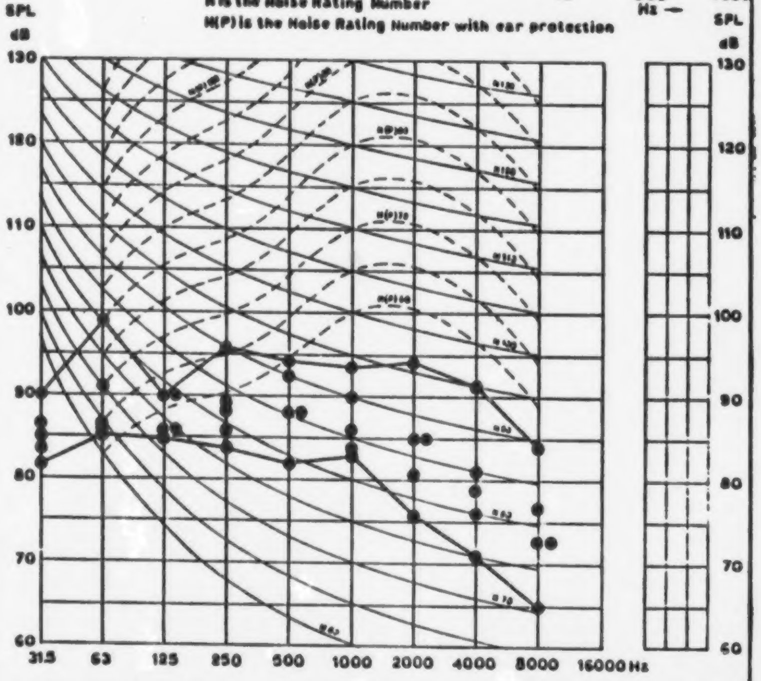
Acoustic environment Reverberant field

Microphon distance Operator



N is the Noise Rating Number

N(P) is the Noise Rating Number with ear protection



Prepared by: M.U.SAVICH

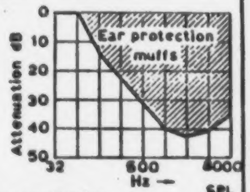
From data by: MAPAO

MINING RESEARCH LABORATORY	NOISE MEASUREMENT IN OCTAVE BANDS	ELLIOT LAKE
Date of measurement 1968	Machine shops	Ontario Metal Mines Page 21 Sign.

No	dB(A)	dB(C)	dB(LIN)	N	N(P)	Note
1	96			93	65	Maximum
2	80			76	-	Minimum
3						
4						

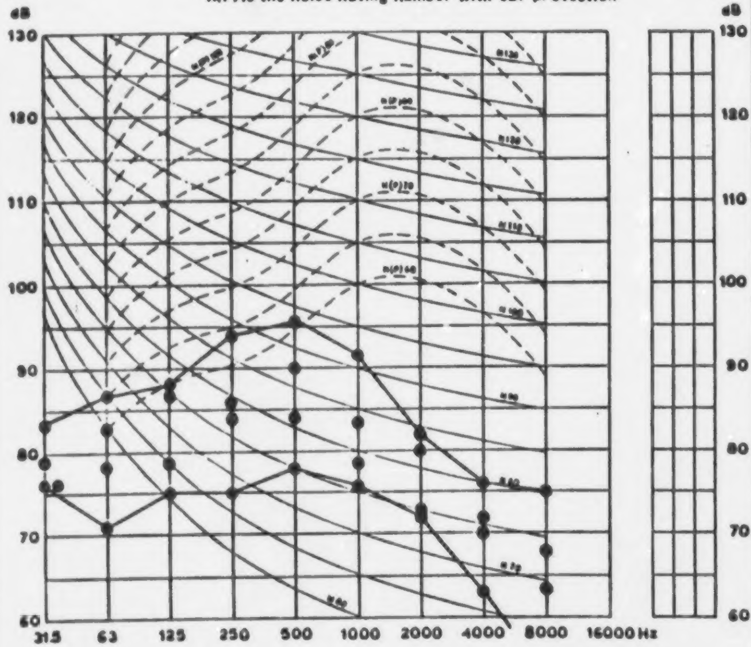
Acoustic environment Reverberant field

Microphon distance ______



N is the Noise Rating Number

N(P) is the Noise Rating Number with ear protection



Prepared by: M.U.SAVICH

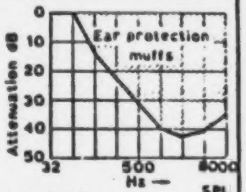
From data by: MAPAO

MINING RESEARCH LABORATORY	NOISE MEASUREMENT IN OCTAVE BANDS	ELLIOT LAKE
Date of measurement 1968	Bit and shank grinding	Ontario Metal Mines Page 22 Sign.

No.	dB(A)	dB(C)	dB(LIN)	N	N(P)	Note
1	110			113	78	Maximum
2	89			87	-	Minimum
3						
4						

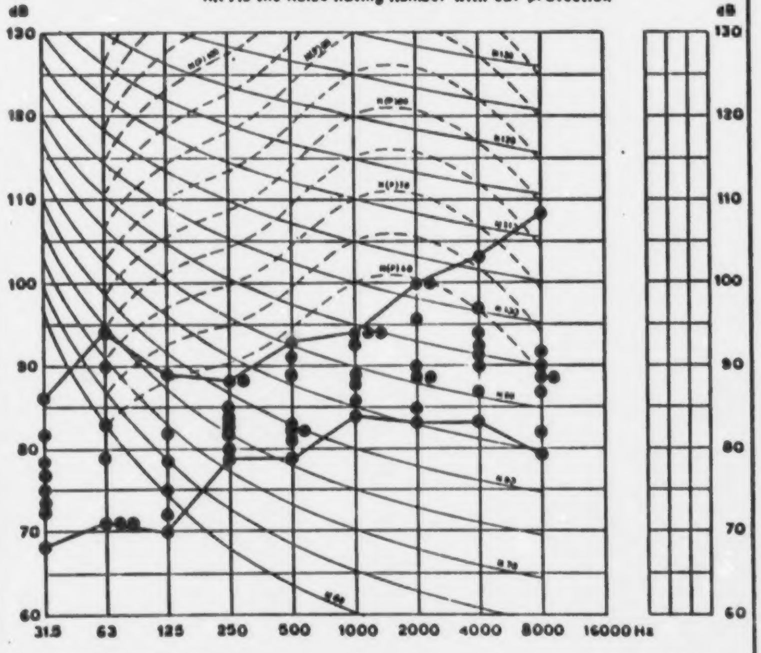
Acoustic environment Reverberant field

Microphon distance Operator



N is the Noise Rating Number

N(P) is the Noise Rating Number with ear protection



Prepared by: M.U.SAVICH

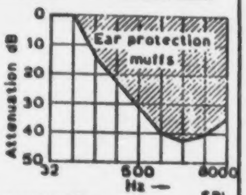
From data by: MAPAO

MINING RESEARCH LABORATORY	NOISE MEASUREMENT IN OCTAVE BANDS	ELLIOT LAKE
Date of measurement 1968	Carpentry shops	Ontario Metal Mines Page 23 Sign.

No	dB(A)	dB(C)	dB(LIN)	N	N(P)	Note
1	91	—	—	93	-	
2	80	—	—	80	-	
3						
4						

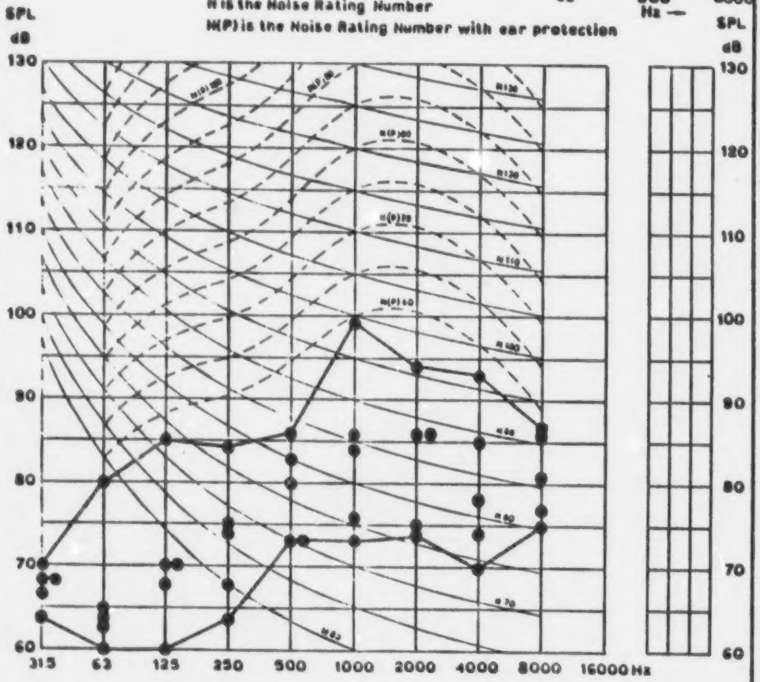
Acoustic environment Reverberant field

Microphon distance ______



N is the Noise Rating Number

N(P) is the Noise Rating Number with ear protection



Prepared by: M U. SAVICH

From data by: MAPAO

MINING - Underground Labor Distribution

TABLE A

GOLD MINES	MINING METHODS	Staff U/G Supt.	Captains	Foremen	Shift bosses	Geologists	Samplers	Engineers	Safety	TOTAL STAFF	Stoping Stope Bosses	Drillers, helpers	Timbermen, helpers	Scalers, Rockbolters	Blasters, Loaders	Fill Men	Slushermen	Loader Operators	Haulage Operators	Muckers	Other	TOTAL STOPING
Aunor Gold Mines	Stope & Pillar	--	3	8	--	1	2	1	1	16	1	80	15	--	--	8	--	--	--	--	--	104
Brant Mines	C & F	1	2	--	4	1	1	2	1	12	--	28	--	--	--	--	4	--	4	4	--	44
Bralorne Resources	C & F	1	--	--	4	--	--	2	1	8	--	25	2	--	--	2	--	2	3	--	--	34
Camflo Mines	Shrink	1	--	--	2	--	2	--	1	6	--	20	2	--	2	--	--	--	--	11	2	37
Dickenson Mines	C & F	1	--	1	5	3	--	6	1	17	--	43	3	--	--	4	--	2	--	--	5	57
East Malartic Mines	S. L. Blast	1	3	2	8	--	--	--	--	14	--	46	--	--	6	--	12	21	--	--	4	89
Giant Yellow Knife	C & F Shrink	1	2	1	9	7	3	12	2	37	--	56	14	--	--	2	--	--	--	--	--	72
Hallnor Mines	C & F	--	1	--	5	1	1	--	1	9	--	54	7	--	--	--	--	--	--	--	--	61
Kerr Addison Mines	C & F	1	5	1	20	--	4	--	1	32	--	265	14	--	--	4	--	--	--	--	--	283
McLeod Mines	C & F	1	1	--	4	--	--	2	--	8	--	6	2	--	2	--	37	2	10	--	--	59
Lamaque Mining Co.	C & F	2	4	--	12	2	5	11	1	37	--	78	26	--	--	--	35	--	46	--	17	202
Marban Gold Mines	Open	1	1	--	3	--	--	--	--	5	28	--	--	--	--	--	2	--	--	--	--	30
Pamour Porcupine Mines	C & F Shrink	1	2	--	8	2	2	2	1	18	--	44	8	--	--	--	--	--	--	--	--	52
Sigma Mines	C & F	1	4	--	13	2	3	11	1	35	1	74	17	--	--	3	14	--	--	--	--	104
Upper Canada Mines	C & F Shrink	1	2	--	4	1	4	2	--	14	--	28	4	--	--	3	--	--	--	--	--	35
Venus Mines	Open	1	--	--	2	1	1	1	1	7	--	8	--	--	--	--	9	--	--	--	--	17
.		15	30	13	103	21	28	52	13	275	30	855	114	--	10	26	113	27	63	15	28	1,281
SILVER MINES																						
Agnico Mines Ltd.	Shrink	1	--	--	4	1	--	2	--	8	--	10	8	--	--	--	4	2	--	1	--	25
Deer Horn Mines	Shrink	--	1	--	2	--	1	1	--	5	--	4	--	--	2	--	2	--	--	2	--	10
Echo Bay Mines	Shrink	1	1	--	2	--	--	--	--	4	--	13	1	--	--	--	--	--	--	--	--	14
Glen Lake	Shrink	1	1	--	4	1	1	2	--	10	--	36	--	--	--	--	--	--	--	--	--	36
Langis Silver & Cobalt	Shrink	1	--	--	2	1	1	2	--	7	--	8	2	--	--	--	2	--	--	--	--	12
Leitch Mines	Open	1	--	--	1	1	--	1	--	4	--	29	--	--	--	--	--	--	--	--	--	29
Manitou Barvue	Shrink	1	1	--	5	3	1	4	1	16	--	14	5	--	2	--	6	--	--	--	--	27
Mastodon-Highland Bell	Open	1	--	--	1	1	--	1	--	4	--	29	--	--	--	--	--	--	--	--	--	29
Siscoe Metals of Ontario	Shrink	--	1	--	2	2	--	3	--	8	--	15	6	--	--	--	--	7	6	1	--	35
Teck Corp.	Open	1	--	--	1	1	--	1	--	4	--	19	--	--	--	--	--	--	--	--	--	19
		8	5	--	24	11	4	16	1	70	--	177	22	--	4	--	14	9	6	4	--	236
URANIUM AND TORIUM MINES																						
Denison Mines Ltd.	Room & Pillar	1	3	1	24	3	3	18	6	59	--	56	--	50	4	--	36	--	--	--	18	164
Eldorado Nuclear Ltd	C & F	1	2	--	9	2	4	24	2	44	--	41	9	--	--	5	--	--	--	--	--	55
Rio Algom (Quirke)	Stope & Pillar	1	5	1	34	8	3	22	--	74	--	89	--	--	--	--	42	--	--	--	--	131
		3	10	2	67	13	10	64	8	177	--	186	9	50	4	5	78	--	--	--	18	350

TABLE A

Development Haulage, Hoisting

GOLD MINES	Loaders	Drillers, Drifting	Drillers, Raising	Timbermen	Loader Operator	Slushermen	Haulage Operators	Muckers	Motor Crew	Other	Other	TOTAL DEVELOP-MENT	Loader Operators	Motormen	Switchmen	Chute Pullers	Dispatcher	Ore, Waste Pass	Crushermen	Skip Tenders	Cage Tenders	Top Men	Hoistmen	Other	TOTAL HAULAGE & HOISTING
Aunor Gold Mines	-	--	--	--	--	--	--	--	--	--	--	--	20	12	--	--	--	5	--	6	6	--	4	--	53
Brant Mines	--	9	9	4	6	--	--	--	--	--	--	28	--	4	--	--	--	--	--	4	--	--	--	--	8
Bralorne Resources	--	--	--	--	--	--	--	--	--	--	--	--	--	5	--	--	--	--	--	5	--	--	10	--	20
Camlo Mines	--	4	4	--	--	--	--	--	--	--	--	8	--	2	--	--	--	--	2	4	--	--	--	--	8
Dickenson Mines	--	8	4	4	--	--	--	--	--	1	--	17	--	--	--	17	--	--	--	4	3	--	--	--	24
East Malartic Mines	--	--	--	17	--	--	--	--	--	--	--	17	--	25	--	5	--	--	4	4	10	--	5	--	53
Giant Yellow Knife	--	8	10	--	--	--	--	--	--	--	--	18	6	4	--	18	--	--	--	5	4	--	7	--	44
Hallnor Mines	--	2	2	4	--	--	--	--	--	--	--	8	10	--	--	--	--	--	--	4	4	--	--	--	18
Kerr Addison Mines	--	--	2	13	--	--	--	--	--	--	--	15	--	24	--	20	--	--	--	4	4	6	--	1	59
McLeod Mines	--	2	--	--	2	1	2	--	--	--	--	7	--	--	--	--	--	--	4	9	--	4	11	--	28
Lamaque Mining Co.	--	4	5	--	--	--	--	4	--	--	--	13	--	6	--	--	--	--	3	8	--	4	8	--	29
Marban Gold Mines	--	2	2	7	--	--	--	--	--	--	--	5	6	12	--	5	--	--	--	3	3	--	3	3	35
Pamour Porcupine Mines	--	10	6	6	--	--	--	--	--	--	--	22	30	20	--	5	--	--	--	2	8	--	1	--	65
Sigma Mines	--	5	4	--	--	--	--	5	6	--	--	20	7	38	--	--	--	3	--	--	12	1	2	--	60
Upper Canada Mines	--	2	2	--	--	--	--	--	--	--	--	4	--	21	--	--	--	2	--	--	5	6	4	--	38
Venus Mines	--	6	2	--	--	--	--	--	--	--	--	8	--	2	--	2	--	--	--	--	--	--	--	--	4
	--	62	52	49	2	1	2	9	6	1	--	184	79	175	--	72	--	5	13	62	53	21	55	4	539
SILVER MINES																									
Agnico Mines Ltd	--	4	4	--	--	--	--	--	--	--	--	8	--	4	--	4	--	--	--	--	4	--	4	--	16
Deer Horn Mines	--	--	--	--	--	--	--	--	--	--	--	--	--	1	1	1	--	--	--	--	2	--	2	--	7
Echo Bay Mines	--	4	--	--	--	--	--	2	--	--	--	6	--	2	2	--	--	--	--	--	2	--	2	--	8
Glen Lake	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7	9	7	--	23
Langis Silver & Cobalt	--	8	1	--	--	--	--	--	2	--	--	11	3	4	--	--	--	--	--	--	4	4	4	--	19
Leitch Mines	--	2	2	--	--		--	--	--	--	--	4	--	2	--	--	--	--	--	--	--	--	--	--	2
Manitou Barvue	-	8	4	--	4	1	--	--	3	--	--	20	7	7	--	4	--	--	10	--	11	4	--	---	43
Mastodon-Highland Bell	--	2	2	--	--	--	--	--	--	--	--	4	---	2	--	--	--	--	--	--	--	--	--	--	2
Siscoe Metals of Ontario	--	4	--	--	--	--	--	--	--	--	--	4	--	--	--	--	--	--	--	--	2	2	4	--	8
Teck Corp	--	2	2	--	--	--	--	--	--	--	--	4	--	2	--	--	--	--	--	--	--	--	--	--	2
	--	34	15	--	4	1	--	2	5	--	--	61	10	24	3	9	--	--	10	--	32	19	23	--	130
URANIUM AND TORIUM MINES																									
Denison Mines Ltd.	--	16	--	--	--	8	--	--	--	8	--	34	18	--	--	13	--	8	--	2	4	2	6	2	55
Eldorado Nuclear Ltd.	--	6	8	--	--	--	--	--	--	--	--	14	--	--	--	8	--	--	1	4	4	3	6	--	26
Rio Algom (Quirke	--	72	28	22	--	17	--	--	--	--	--	139	--	20	--	20	--	--	3	5	5	8	5	7	73
	--	96	36	22	--	25	--	--	--	8	--	187	18	20	--	41	--	8	4	11	13	13	17	9	154

TABLE A

General

GOLD MINES	Pipe Fitters	Trackmen	Pumpmen	Ventilation Crew	Warehousemen	Lampmen	Riggers	Fill Preparation	General Labor	Mechanics	Electricians	Steel, bit Grinders	Exploration Drillers	Other	Other	TOTAL GENERAL	TOTAL MINE
Auner Gold Mines	4	2	1	--	--	--	--	--	--	--	--	--	--	--	--	7	180
Brant Mines	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	4	92
Bralorne Resources	1	2	--	--	1	1	--	1	--	5	3	1	--	--	--	15	77
Camflo Mines	--	--	--	--	--	--	--	--	--	--	—	--	--	--	--	--	59
Dickenson Mines	--	--	--	1	--	--	--	8	2	2	--	--	--	1	4	18	133
East Malartic Mines	2	2	--	--	--	1	--	--	--	7	--	--	--	3	1	16	190
Giant Yellow Knife	4	7	--	2	9	1	2	--	17	10	8	1	25	2	2	2	261
Hallnor Mines	1	--	--	--	--	--	--	4	--	2	--	--	--	2	1	10	106
Kerr Addison Mines	--	1	--	--	2	--	--	--	--	--	--	--	3	4	5	15	406
McLeod Mines	1	2	--	--	--	4	--	--	--	2	--	1	--	1	--	11	113
Lamaque Mining Co.	36	--	--	--	2	1	--	2	--	9	5	2	--	5	--	62	363
Marban Gold Mines	1	--	--	--	--	1	--	--	--	1	--	--	--	1	1	5	80
Pamour Porcupine Mines	3	5	1	--	3	1	--	--	2	--	--	--	4	1	--	20	177
Sigma Mines	5	8	--	--	3	1	--	--	--	2	2	--	--	11	15	48	239
Upper Canada Mines	3	--	1	--	2	--	1	3	--	1	--	2	--	1	7	27	112
Venus Mines	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	1	30
·	61	29	3	3	22	11	3	18	22	41	18	7	32	32	36	338	2,617
SILVER MINES																	
Agnico Mines Ltd.	--	--	--	--	--	--	--	--	1	2	--	1	--	--	--	4	61
Deer Horn Mines	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	1	23
Echo Bay Mines	--	1	--	--	--	--	--	--	2	1	--	1	1	--	--	6	38
Glen Lake	--	--	--	--	--	--	--	--	--	3	3	1	1	--	--	8	77
Langis Silver & Cobalt	--	--	1	--	--	--	--	--	--	1	1	--	1	2	--	6	55
Leitch Mines	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	39
Manitou Barvue	3	2	1	--	--	3	--	--	--	6	4	1	--	--	--	20	126
Mastodon-Highland Bell	--	--	--	--	1	--	--	--	--	4	1	--	7	--	--	13	52
Siscoe Metals of Ontario	1	1	--	--	--	--	--	--	--	--	--	1	--	1	--	4	59
Teck Corp.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	29
	4	4	2	--	1	3	--	--	3	18	9	5	10	3	--	62	559
URANIUM AND TORIUM MINES																	
Denison Mines Ltd.	7	2	--	6	2	6	9	4	--	66	20	--	2	8	--	132	444
Eldorado Nuclear Ltd.	2	3	--	4	1	2	--	3	2	5	6	2	--	1	2	33	178
Rio Algom (Quirke)	13	12	2	6	--	1	--	--	11	21	16	--	--	5	14	101	518
	22	17	2	16	3	9	9	7	13	92	42	2	2	14	16	266	1,134

MINING - Underground Labor Distribution

TABLE B

		Staff									Stoping										
COPPER MINES	MINING METHODS	U/G supt.	Captains	Foremen	Shift bosses	Geologists	Samplers	Engineers	Safety	TOTAL STAFF	Stope bosses	Drillers, helpers	Timbermen, helpers	Scalers, rockbolters	Blasters, Loaders	Fill men	Slushermen	Loader operators	Haulage operators	Muckers	Other	TOTAL STOPING
American Sm & R	C & F	3	--	3	9	1	2	6	1	25	--	136	48	--	--	--	--	--	--	--	--	184
Anglo Rouyn Mines	Shrink Open pit	1	2	--	6	2	--	8	1	19	--	41	2	--	--	--	4	3	--	--	--	50
Atlantic Coast Copper	-----	1	1	1	4	2	--	4	1	14	--	3	4	--	2	--	--	--	--	--	--	9
Brines	Open	1	1	--	5	1	--	4	1	13	--	2	--	--	2	--	--	--	--	--	--	4
Bruneau Mines	Shrink	1	--	1	--	--	--	1	--	3	--	12	2	--	--	--	--	--	--	2	--	16
Can. Jamieson Mines	Shrink	1	--	--	4	1	--	3	--	9	--	22	2	--	--	--	7	--	--	--	--	31
Consol Rambler Mines	L. H. Caving	1	1	--	5	1	1	4	1	14	--	4	2	1	2	--	--	4	7	10	--	30
Craigmont Mines Ltd.	Sub. Lev. Cave	1	1	4	16	--	--	2	1	25	--	24	--	--	16	--	--	16	--	8	--	64
Gaspe Copper Mines	Room & Pillar	1	4	1	7	4	1	6	1	25	--	18	--	53	6	--	--	8	16	--	1	104
Granduc Operating Co.	-----	1	4	11	15	--	--	--	--	31	--	--	--	--	--	--	--	--	--	--	--	--
Gullbridge Mines	L. H. Sub. Lev.	1	1	1	4	1	--	3	1	12	--	--	4	--	2	--	24	--	8	--	8	46
Jameland Mines	L. H.	--	1	--	4	1	--	1	--	7	--	22	2	--	2	--	--	4	--	--	--	30
Kam Kotia Mines	L. H.	1	2	--	6	1	--	1	1	12	--	20	3	--	2	--	18	--	--	--	--	43
Kidd Copper Mines	Shrink	1	--	--	4	1	--	1	1	8	--	--	--	--	--	--	--	--	--	--	--	--
Lake Dufault Mines	Open	1	1	--	2	2	2	4	--	12	--	5	--	--	2	--	--	--	--	--	--	7
Madeleine Mines	B. H.	1	-	--	3	--	--	--	--	4	--	10	1	1	9	--	--	--	--	--	--	21
Madsen Red Lake	C & F	1	1	1	5	--	2	--	--	10	--	54	2	--	--	2	--	1	5	--	--	64
McIntyre Porcupine	S. L.	1	4	1	21	--	3	--	--	30	1	139	16	--	6	8	7	11	10	--	--	196
Mines de Poirier	B. H. C & F	1	2	1	6	3	3	4	2	22	--	60	14	4	2	2	--	--	—	--	--	82
Noranda Mines	C & F	1	3	--	12	3	2	5	3	29	15	11	--	--	10	--	38	--	--	--	17	91
Normetal Mines	C & F	2	2	--	14	--	2	1	2	23	90	90	--	--	--	--	--	--	--	--	--	180
Opemiska Copper Mines	C & F	2	6	2	21	--	--	--	--	31	4	162	26	--	4	2	4	--	--	--	4	206
Quemont Mines	Sub Level	--	2	--	8	1	1	8	1	21	2	58	13	--	1	2	4	--	--	--	6	86
Sherritt Gordon Mines	L. H.	1	--	3	5	1	--	9	1	20	--	12	4	2	8	--	--	--	--	--	[illegible]	35
Tribag Mining Co.	Shrink B. H.	1	2	--	3	--	--	--	--	6	--	18	4	--	--	--	8	--	--	--	--	30
Upper Beaver Mines	Shrink	--	1	--	4	1	4	--	--	10	--	37	4	--	--	--	--	--	--	--	--	41
Willroy Mines	Open	1	1	--	6	--	--	--	--	8	--	38	6	4	4	--	20	6	--	6	--	84
		28	42	30	199	27	23	75	19	443	112	998	159	65	80	16	134	53	48	26	45	1,736
LEAD MINES																						
Brunswick M & S	L. H. C & F	1	4	--	17	3	2	19	--	46	4	14	10	--	19	--	18	8	8	--	18	97
Heath Steele Mines	B. H.	2	1	1	7	--	--	--	--	11	--	21	5	--	7	--	--	--	--	--	--	33
Nigadoo River Mines	C & F Shrink	1	2	--	8	1	1	6	--	19	--	32	14	1	2	4	8	8	--	--	--	69
Reeves MacDonald	B. H.	--	--	1	3	--	1	--	--	5	--	4	1	1	--	--	3	--	--	--	--	9
United Keno Hill	Sq. Set & Cap	1	4	1	6	3	--	6	1	22	1	60	15	--	--	--	--	--	--	--	--	76
		5	11	3	41	7	4	31	1	103	5	131	45	2	28	4	27	16	8	--	18	284

TABLE B

COPPER MINES	Development												Haulage, Hoisting											
	Loaders	Drillers, Drifting	Drillers, Raising	Timbermen	Loader operators	Slushermen	Haulage operators	Muckers	Motor Crew	Other	Other	TOTAL DEVELOPMENT	Loader operators	Motormen	Switchmen	Chute pullers	Dispatcher	Ore, Waste pass	Crushermen	Skip tenders	Cage tenders	Top men	Hoistmen	Other	TOTAL HAULAGE & HOISTING
American Sm & R	--	8	8	--	--	--	--	--	--	--	--	16	--	10	--	10	--	--	--	3	6	4	10	--	43
Anglo Rouyn Mines	--	32	6	1	6	--	6	--	--	--	--	51	--	4	--	4	--	1	--	3	--	2	3	1	18
Atlantic Coast Copper	--	8	2	--	--	--	--	--	--	--	--	10	27	--	--	--	--	--	3	4	--	3	4	--	41
Brunen	--	8	8	--	--	--	--	--	--	--	--	16	12	--	--	--	--	--	3	--	6	1	5	--	27
Bruneau Mines	--	2	4	--	--	--	--	--	2	--	--	8	--	1	1	--	--	--	--	--	--	--	--	--	2
Can. Jamieson Mines	--	4	--	--	--	--	--	--	--	--	--	4	12	--	--	9	--	--	--	4	--	2	--	--	27
Consol Rambler Mines	8	6	2	2	--	--	--	--	--	--	--	18	--	--	--	--	1	--	4	4	--	4	4	--	17
Craigmont Mines Ltd.	--	24	8	36	4	--	--	4	--	--	--	76	8	8	--	--	--	--	--	--	8	--	--	--	24
Gaspe Copper Mines	--	28	--	2	--	--	--	--	--	--	--	30	--	--	--	--	--	--	--	--	2	--	--	3	5
Granduc Operating Co.	--	--	--	7	--	--	--	--	--	91	8	106	15	22	2	--	1	--	--	--	3	--	3	4	50
Gullbridge Mines	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	8	--	--	4	4	2	1	4	--	23
Jameland Mines	--	4	4	--	--	--	--	--	--	--	--	6	--	4	--	4	--	--	--	2	--	2	2	--	14
Kam Kotia Mines	--	--	--	--	--	--	--	--	--	--	--	--	10	26	--	12	--	--	3	4	--	4	4	--	63
Kidd Copper Mines	--	--	--	--	—	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3	4	1	6	--	14
Lake Dufault Mines	--	6	8	--	--	--	--	--	--	--	--	14	3	--	--	--	--	--	2	2	--	--	2	--	9
Madeleine Mines	--	10	4	2	--	--	6	--	--	--	--	22	6	2	--	--	--	--	--	--	--	--	--	--	8
Madsen Red Lake	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7	--	--	1	2	2	3	--	--	15
McIntyre Porcupine	--	28	14	--	--	--	--	--	--	--	--	42	--	6	--	24	--	3	5	5	10	3	--	3	59
Mines de Poirier	--	12	4	--	--	--	--	--	--	16	--	32	16	16	--	--	--	--	2	4	--	5	4	--	47
Noranda Mines	23	46	5	12	--	--	--	--	--	--	--	86	--	--	--	--	--	--	--	6	6	--	6	--	18
Normetal Mines	2	2	--	--	4	--	--	--	--	--	--	8	--	44	--	--	--	--	--	--	20	4	10	--	78
Opemiska Copper Mines	--	27	9	16	--	--	--	--	--	--	--	52	10	31	--	--	5	--	--	8	5	7	--	2	68
Quemont Mines	--	6	2	--	2	--	--	4	--	2	--	16	--	6	--	--	--	--	5	2	5	4	7	5	34
Sherritt Gordon Mines	10	10	2	--	--	--	--	3	--	2	--	27	15	--	--	--	--	--	--	4	4	4	4	4	35
Tribag Mining Co.	--	6	2	--	--	--	--	--	--	--	--	8	6	10	--	8	--	--	--	--	4	--	--	--	28
Upper Beaver Mines	--	4	4	--	--	--	--	--	--	--	--	8	--	18	--	--	--	--	--	--	6	8	6	--	36
Willroy Mines	2	11	--	--	--	--	--	--	--	--	--	13	--	--	--	--	--	--	3	--	5	--	--	2	10
	45	292	96	78	16	--	12	11	2	111	8	671	140	208	3	86	7	4	35	64	98	62	84	24	815
LEAD MINES																									
Brunswick M & S	--	56	14	10	--	--	--	2	--	6	8	96	--	--	--	--	--	4	8	4	8	4	8	--	36
Heath Steele Mines	--	42	--	--	--	--	--	--	2	--	--	44	8	--	--	--	--	--	5	9	--	--	8	--	30
Nigadoo River Mines	8	8	5	--	8	2	2	--	--	--	--	33	--	16	--	8	--	2	--	--	8	2	1	5	42
Reeves MacDonald	--	8	3	4	7	--	--	--	--	--	--	22	--	5	--	3	--	--	--	3	--	--	3	--	14
United Keno Hill	--	12	22	--	--	--	--	--	--	--	--	34	1	12	12	--	--	--	--	--	3	3	3	2	36
	8	126	44	14	15	2	2	2	2	6	8	229	9	33	12	11	--	6	13	16	19	9	23	7	158

TABLE B

General

COPPER MINES	Pipe fitters	Trackmen	Pumpmen	Ventilation Crew	Warehousemen	Lampmen	Riggers	Fill preparation	General Labor	Mechanics	Electricians	Steel, bit grinders	Exploration Drillers	Other	Other	TOTAL GENERAL	TOTAL MINE
American Sm & R	7	2	4	--	--	4	--	4	--	4	4	2	1	--	--	32	300
Anglo Rouyn Mines	4	2	--	--	--	--	--	--	--	--	--	--	--	2	1	9	147
Atlantic Coast Copper	--	2	--	--	1	1	--	--	5	3	2	--	2	--	--	16	90
Brines	--	--	--	--	--	1	--	--	10	10	2	--	2	--	--	25	85
Bruneau Mines	--	--	--	--	--	--	--	--	--	4	--	--	--	--	--	4	33
Con. Jamieson Mines	--	--	--	--	--	1	--	--	1	--	--	--	--	--	1	3	74
Consol Rambler Mines	1	2	1	2	--	--	--	--	1	8	3	1	1	--	--	20	99
Craigmont Mines Ltd.	8	6	--	--	4	1	--	--	16	46	8	--	--	12	--	101	290
Gaspe Copper Mines	--	2	--	--	2	4	--	--	2	--	--	--	--	2	2	14	178
Granduc Operating Co.	--	27	--	--	1	1	--	--	20	31	23	--	--	4	5	112	299
Gullbridge Mines	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	81
Jameland Mines	--	--	--	--	--	--	--	--	--	2	--	--	4	--	4	10	69
Kam Kotia Mines	--	--	--	--	--	1	--	--	--	3	4	2	3	--	2	15	133
Kidd Copper Mines	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	22
Lake Dufault Mines	--	--	--	--	--	1	--	--	--	--	--	1	--	2	--	4	46
Madeleine Mines	1	--	--	1	--	--	--	--	2	--	--	--	2	6	--	12	87
Madsen Red Lake	--	1	--	--	--	--	--	--	--	7	--	--	--	--	--	8	97
McIntyre Porcupine	6	6	1	1	--	1	8	2	16	16	--	1	5	2	--	65	394
Mines de Poirier	2	2	--	2	--	1	--	--	10	8	1	1	12	2	--	21	224
Noranda Mines	--	8	--	--	9	1	6	1	42	10	6	2	--	--	--	85	309
Normetal Mines	4	5	2	3	1	1	--	2	12	10	--	--	1	3	22	66	355
Opemiska Copper Mines	4	--	--	10	--	4	--	--	21	--	--	3	--	1	3	46	403
Quemont Mines	3	2	2	--	--	1	--	2	--	--	--	--	--	3	--	13	170
Sherritt Gordon Mines	--	--	1	--	2	1	--	--	5	12	4	1	8	--	--	34	151
Tribag Mining Co.	--	1	1	--	--	--	--	--	--	--	--	--	--	--	--	2	74
Upper Beaver Mines	4	2	--	--	--	--	--	--	--	--	--	--	--	--	--	19	116
Willroy Mines	--	2	2	--	--	--	--	--	--	---	--	--	--	--	--	4	119
	44	72	14	19	20	25	14	11	173	174	57	14	41	39	40	760	4.425
LEAD MINES																	
Brunswick M & S	--	--	--	--	--	2	--	--	46	21	4	1	9	4	4	96	371
Heath Steele Mines	--	--	--	--	--	--	--	--	46	--	--	--	--	3	1	49	167
Nigadoo River Mines	--	2	4	--	--	2	--	4	18	--	--	--	--	--	--	30	193
Reeves MacDonald	--	2	--	--	--	--	--	--	--	2	--	--	1	--	--	5	55
United Keno Hill	2	1	--	--	--	--	--	--	8	4	--	[illegible]	3	[illegible]	--	19	187
	2	5	4	--	--	4	--	4	118	27	4	2	13	7	5	199	973

MINING - Underground Labor Distribution

TABLE C

		Staff									Stoping											
IRON ORE MINES	MINING METHODS	U/G Supt.	Captains	Foremen	Shift bosses	Geologists	Samplers	Engineers	Safety	TOTAL STAFF	Stope Bosses	Drillers helpers	Timbermen, helpers	Scalers, Rockbolters	Blasters, Loaders	Fill Men	Slushermen	Loader operators	Haulage operators	Muckers	Other	TOTAL STOPING
Algoma Ore Div.	Open																					
(MacLeod)	Stope & Pillar	1	--	4	13	2	2	7	2	36	4	--	--	--	10	--	14	--	4	--	5	43
Tenado Mines	L. H. Open	1	1	2	9	2	1	5	1	22	--	9	--	2	9	--	--	10	--	--	5	35
		2	1	6	22	4	3	12	3	53	4	9	--	2	25	--	14	10	4	--	10	78
NICKEL MINES																						
Consolidated Con. Faraday Ltd.	L. H. C & F	1	--	--	2	--	--	--	--	3	--	4	2	--	1	--	--	10	--	--	--	17
Dumbarton Mines Ltd.	L. H.	1	--	--	2	--	--	--	--	3	--	4	--	--	2	--	--	--	3	--	--	9
Giant Mascot Mines	B. H.	2	--	3	9	--	--	--	--	14	--	10	2	--	2	--	3	18	9	--	--	44
Sherritt Gordon	B. H.	3	--	--	17	6	--	11	4	41	--	32	7	--	17	--	--	28	--	--	3	87
		7	--	3	30	6	--	11	4	61	--	50	11	--	22	--	3	56	12	--	3	157
ZINC MINES																						
Key Anacon Mines	L. H.	--	1	--	1	1	1	2	--	6	--	--	--	--	--	--	--	--	--	--	--	--
Mattagami Lake Mines	S. L.	2	2	--	14	2	1	6	2	31	--	20	25	--	10	1	15	--	--	--	2	73
Orchan Mines	C & F B. H.	1	1	--	4	1	1	5	1	14	--	38	4	--	2	1	3	--	3	--	3	53
Sullivan Mining Group	C & F	1	4	1	8	2	1	1	7	25	--	67	4	--	--	6	--	2	--	--	--	79
Texas Gulf (Kidd Creek)	---	2	1	--	4	--	--	2	--	9	--	--	--	--	--	--	--	--	--	--	--	--
Zenmac Metal	Open	--	1	--	--	--	--	1	--	2	--	10	--	--	--	--	--	--	--	--	--	10
		6	10	1	31	6	4	17	10	87	--	135	33	--	12	8	18	2	3	--	5	215
MOLYBDENUM MINES																						
KRC Operators Ltd.	Open B. H.	--	1	--	2	1	--	2	1	7	--	6	--	--	--	--	3	6	--	--	--	15
Molybdenite Corp. of Canada	Shrink Open	1	1	--	4	2	--	2	--	10	--	22	6	--	--	--	--	--	--	--	--	28
Preissac Molybdenite	Shrink Open L. H.	1	1	3	5	1	1	5	1	18	--	30	22	1	--	--	13	--	23	23	--	112
		2	3	3	11	4	1	9	2	35	--	58	28	1	--	--	16	6	23	23	--	155
OTHER METALS MINES																						
Canadian Ex. (Invincible)	R. & P.	2	--	--	4	3	--	3	1	13	--	33	--	--	--	--	--	--	--	--	--	33
St. Lawrence Columbium	L. H.	1	1	--	4	--	--	--	--	6	--	10	--	--	4	--	--	--	--	--	1	15
Tantalum Mining Corp.	R. & P	1	--	--	2	--	--	--	--	3	--	3	--	2	2	--	--	3	--	--	--	10
		4	1	--	10	3	--	3	1	22	--	46	--	2	6	--	--	3	--	--	1	58
NON METALS MINES																						
Asbestos Corp. (King Beaver)	B. C.	2	1	9	--	--	--	1	--	13	--	--	--	--	--	--	27	--	--	--	--	27
Dumtar Caledonia	Room Pillar	1	--	2	--	--	--	--	--	3	--	2	--	1	3	--	--	2	5	1	--	14
Newfoundland Fluorspar	C & F	1	2	--	6	1	1	4	1	16	--	--	--	--	--	--	--	--	--	--	1	1
		4	3	11	6	1	1	5	1	32	--	2	--	1	3	--	27	2	5	1	1	42

TABLE C

	Development												Haulage, Hoisting												
IRON ORE MINES	Loaders	Drillers, Drifting	Drillers, Raising	Timbermen	Loader Operators	Slushermen	Haulage Operators	Muckers	Motor Crew	Other	Other	TOTAL DEVELOPMENT	Loader Operators	Motormen	Switchmen	Chute Pullers	Dispatcher	Ore, Waste Pass	Crushermen	Skip Tenders	Cage Tenders	Top Men	Hoistmen	Other	TOTAL HAULAGE & HOISTING
Algoma Ore Div.																									
(MacLeod)	6	24	32	5	8	--	1	5	5	--	12	97	6	4	--	--	--	--	4	--	6	--	4	1	25
Tenado Mines	--	15	2	--	5	--	--	--	--	2	--	24	--	--	--	--	--	3	3	3	3	--	--	--	12
	6	39	34	5	13	--	--	5	5	2	12	121	6	4	--	--	--	3	7	3	9	--	4	1	37
NICKEL MINES																									
Consolidated Can. Faraday Ltd.	--	2	--	--	--	--	--	--	--	--	--	2	--	1	--	--	--	--	--	2	--	--	--	--	3
Dumbarton Mines Ltd.	--	6	2	--	--	--	2	--	--	--	--	10	--	--	--	--	--	--	2	--	--	--	--	--	2
Giant Mascot Mines	--	19	6	--	3	--	--	--	--	--	12	40	--	--	--	--	--	--	--	--	3	--	3	--	6
Sherritt Gordon	--	23	19	--	--	--	--	--	--	3	--	45	--	12	--	8	--	--	9	4	11	1	16	22	83
	--	50	27	--	3	--	2	--	--	3	12	97	--	13	--	8	--	--	11	6	14	1	19	22	94
ZINC MINES																									
Key Anacon Mines	6	4	2	--	--	--	--	--	--	--	--	12	--	--	--	--	--	--	--	1	2	1	2	--	6
Mattagami Lake Mines	--	20	4	2	6	--	--	--	4	4	--	40	--	15	--	--	--	--	3	3	5	6	--	--	32
Orchan Mines	--	4	2	--	--	--	--	3	--	--	--	9	--	2	--	2	--	--	2	--	3	1	--	--	10
Sullivan Mining Group	--	12	12	14	--	--	--	--	--	12	5	55	--	3	--	3	--	--	--	16	--	3	9	--	34
Texas Gulf (Kidd Creek)	9	12	2	2	--	--	9	--	--	--	--	34	--	--	--	--	--	--	--	--	--	--	--	--	--
Zemmac Metal	--	--	--	--	--	—	--	--	--	--	1	7	--	--	--	--	--	--	--	--	1	1	1	--	3
	15	52	22	18	6	--	9	3	4	16	6	151	--	20	--	5	--	--	5	20	11	12	12	--	85
MOLYBDENUM MINES																									
KRC Operators Ltd.	--	4	--	--	--	--	--	--	--	--	--	4	--	2	--	--	--	--	--	--	--	--	2	--	4
Molybdenite Corp. of Canada	--	5	1	--	5	--	--	--	2	--	--	13	5	17	--	19	--	--	--	4	--	2	-	6	53
Preissac Molybdenite	--	5	5	--	--	--	--	4	4	--	--	18	--	--	--	--	--	--	--	3	--	2	4	6	15
	--	14	6	--	5	--	--	4	6	--	--	35	5	19	--	19	--	--	--	7	--	4	6	12	72
OTHER METALS MINES																									
Canadian Ta. (Invincible)	--	6	--	--	--	--	--	--	--	--	--	6	3	--	--	--	--	--	--	--	--	--	-	5	8
St. Lawrence Columbium	--	16	4	4	--	--	--	2	--	--	--	26	9	--	--	--	--	--	5	--	4	--	4	2	24
Tantalum Mining Corp.	--	4	--	--	--	--	--	--	--	--	--	4	--	1	--	--	--	--	--	1	--	--	2	--	4
	--	26	4	4	--	--	--	2	--	--	--	36	12	1	--	--	--	--	5	1	4	--	6	7	36
NON METALS MINES																									
Asbestos Corp. (King Beaver)	--	51	--	--	--	--	9	--	--	31	14	105	--	6	--	--	--	--	7	--	6	--	9	3	31
Domtar Caledonia	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2	--	--	--	2	1	5
Newfoundland Fluorspar	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	4	--	7	3	10	--	24
	--	51	--	--	--	--	9	--	--	31	14	105	--	6	--	--	--	--	13	--	13	3	21	4	60

TABLE C

General

IRON ORE MINES	Pipe Fitters	Trackmen	Pumpmen	Ventilation Crew	Warehousemen	Lampmen	Riggers	Fill Preparation	General Labor	Mechanics	Electricians	Steel, bit grinders	Exploration Drillers	Other	Other	TOTAL GENERAL	TOTAL MINE
Algoma Ore Div.																	
(MacLeod)	1	1	1	--	1	1	--	--	3	35	5	2	--	1	3	54	255
Tonado Mines	--	--	--	--	--	1	--	--	6	--	--	--	--	2	--	9	102
	1	1	1	--	1	2	--	--	9	35	5	2	--	3	3	63	357
NICKEL MINES																	
Consolidated Can. Faraday Ltd.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	25
Dumbarton Mines Ltd.	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	1	25
Giant Mascot Mines	--	2	--	--	--	--	--	--	--	--	--	--	--	--	--	2	106
Sherritt Gordon	--	--	--	--	--	1	--	--	--	28	10	2	33	2	6	82	338
	--	2	--	--	--	2	--	--	--	28	10	2	33	2	6	85	494
ZINC MINES																	
Key Anacon Mines	--	1	--	--	--	--	--	1	2	1	3	3	--	--	--	11	35
Mattagami Lake Mines	4	3	--	--	--	--	--	6	9	17	5	4	--	4	1	53	229
Orchan Mines	1	1	--	--	--	2	--	--	2	--	--	--	6	1	2	15	102
Sullivan Mining Group	3	2	--	--	--	--	--	4	5	7	--	2	--	2	--	25	217
Texas Gulf (Kidd Creek)	5	--	--	2	--	--	--	--	--	--	--	1	6	1	1	16	59
Zenmac Metal	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	4	17
	13	7	--	2	--	2	--	11	18	26	8	10	12	8	4	121	659
MOLYBDENUM MINES																	
KRC Operators Ltd.	--	--	--	--	--	--	--	--	--	2	2	--	1	--	--	5	35
Molybdenite Corp. of Canada	2	4	--	--	--	--	--	2	--	2	--	--	--	--	--	10	114
Preissac Molybdenite	--	4	1	--	--	2	--	--	2	2	4	3	3	--	--	21	184
	2	8	1	--	--	2	--	2	2	6	6	3	4	--	--	36	333
OTHER METALS MINES																	
Canadian Ex. (Invincible)	2	--	--	--	--	--	--	--	--	--	--	1	--	1	2	6	66
St. Lawrence Columbium	--	--	--	--	--	1	--	--	--	--	--	--	4	--	--	5	76
Tantalum Mining Corp.	--	1	--	--	--	--	--	--	1	--	--	--	--	--	--	2	23
	2	1	--	--	--	1	--	--	1	--	--	1	4	1	2	13	165
NON METALS MINES																	
Asbestos Corp. (King Beaver)	1	1	--	--	--	--	--	--	63	6	5	1	--	4	4	85	261
Domtar Caledonia	--	--	--	--	--	--	--	--	1	2	--	--	--	--	--	3	25
Newfoundland Fluorspar	--	--	4	--	--	1	--	--	--	5	--	1	2	--	--	13	54
	1	1	4	--	--	1	--	--	64	13	5	2	2	4	4	101	340

MILL FORCE

TABLE D

Staff

	Superintendent, Assistant	Foremen	Shift bosses	Metallurgists, Chemists	Mill Engineer	Chief Assayer, Assistant	Clerk, Typists	Mech. Maint. foremen	Other	Other	TOTAL STAFF
Advocate Mines	1	3	--	--	--	--	2	1	3	--	10
Annice Mines	1	--	--	--	--	2	--	--	--	--	3
Algoma Ore	2	1	4	3	--	--	1	1	--	--	12
Anglo-Rouyn Mines	--	1	--	--	--	1	--	--	--	--	2
Aunor Gold Mines	1	1	1	--	--	--	--	--	--	--	3
Bethlehem Copper	2	2	5	4	--	3	2	2	--	-	20
Bralorne Can-Fer	1	--	--	--	--	--	--	--	--	--	1
Brenda Mines	1	1	5	2	1	2	1	2	--	--	15
British Columbia Molybdenum	1	2	5	2	2	4	1	2	--	--	19
Brunswick M. & S.	2	5	8	4	--	2	4	5	4	--	37
Camflo Mines	1	1	--	--	--	1	--	--	--	--	3
Canadian Expl. Tungsten	1	1	5	2	--	1	1	--	4	--	15
Canadian Jamieson	1	--	4	--	--	3	1	--	--	--	9
Cassiar Asbestos Clinton	2	1	5	--	--	--	1	--	8	--	17
Consol. Cdn. Faraday	1	1	3	--	1	4	--	--	--	--	10
Consol. Rambler	1	1	3	--	--	2	--	1	--	--	8
Craigmont Mines	2	2	4	1	1	1	--	--	2	2	15
Deer Horn Mines	1	--	--	--	--	--	--	--	--	--	1
Denison Mines	1	3	8	2	2	2	1	4	1	1	25
Dickenson Mines	1	--	--	1	--	2	--	--	--	--	4
Dresser Minerals	1	1	--	--	--	2	--	--	--	--	4
East Malartic	1	--	6	--	--	2	--	--	--	--	9
Echo Bay Mines	1	--	--	--	--	2	--	--	--	--	3
Eldorado Nuclear	2	1	6	1	2	4	1	--	1	2	20
Endako Mines	2	5	5	4	--	2	1	--	8	--	27
Gaspe Copper	--	--	--	--	--	--	--	--	--	--	11
Giant Mascot Mines	2	--	1	--	--	2	--	--	--	--	5
Giant Yellowknife	1	2	4	1	1	2	1	--	1	--	13
Granby Mining (Phoenix)	2	--	--	--	--	2	--	--	--	--	4
Granduc Operating	2	1	--	2	--	--	1	--	--	--	6
Granisle Copper	1	2	4	1	--	1	--	1	--	--	10
Griffith Mine	1	11	--	3	4	7	--	10	8	4	47
Gullbridge Mines	1	1	4	--	--	1	1	1	--	--	9
Hallnor Mines	1	1	--	--	--	--	--	--	--	--	2
Heath Mines	1	2	4	1	1	2	1	1	--	--	13
Indusmin	1	1	4	--	--	1	--	--	--	--	7
Iron Ore Co. (Carol)	2	3	23	4	5	--	3	23	3	--	65
Iron Ore Co. (Schefferville)	--	--	--	--	--	--	--	--	--	--	--
Jones & Laughlin (Adams)	2	1	8	1	--	1	2	4	2	--	20
Jameland Mines	--	--	--	--	--	--	--	--	--	--	--
Kam Kotia Mines	1	1	2	2	--	1	--	--	--	--	7
Kerr Addison	2	1	4	2	--	1	--	--	--	--	10
KRC Operators (Mt. Copeland)	1	1	--	--	--	2	--	--	--	--	4
Kidd Copper	1	--	--	--	--	1	--	--	--	--	2
Lake Asbestos	1	3	3	--	1	1	1	1	--	--	11
Lake Shore McLeod-Mosher	2	--	3	--	4	--	--	--	--	--	9
Lamaque Mining	2	1	--	--	--	--	--	1	--	--	4
Leitch Mastodon H. B.	1	--	--	--	--	1	--	--	--	--	2
Madeleine, Les Mines	1	1	4	1	--	3	1	2	--	--	13
Madsen Red Lake	1	2		--	--	1	--	--	--	--	4
Malartic Gold Fields	2	1	4	--	--	1	1	1	--	--	10
Manitou Barvue	2	1	4	--	1	1	1	1	--	--	11
Mattagami Lake	2	1	5	1	--	2	1	1	--	--	13
McIntyre Porcupine	1	1	4	2	--	1	1	1	1	--	12
National Steel (Moose Mt.)	2	4	--	1	--	2	1	6	--	--	16
New Imperial	1	5	--	1	1	1	--	--	--	--	9
Nigadoo River	1	1	4	--	--	[illegible]	1	1	--	-	[illegible]
Noranda (Geco)	1	4	4	1	1	2	3	1	1	2	20
Noranda (Horne)	1	1	4	3	--	--	1	1	1	2	14
Normetal	2	--	4	--	--	2	1	1	1	--	13
Opemiska Copper	1	1	4	--	1	1	1	1	--	--	10
Orchan Mines	1	1	4	1	--	1	1	1	1	--	11
Pamour Porcupine	2	2	4	[illegible]	--	[illegible]	--	--		--	14
Piclands Mather Hilton	1	2	8	1	--	1	3	--	--	--	16
Preissac Molybdenite	1	1	--	1	--	--	1	--	-	--	4
Quemont Mines	1	2	6	2	--	1	2	1	6	1	22
Red Mountain Mines	--	1	--	--	--	1	--	--	--	--	2
Reeves MacDonald	1	1	--	--	--	3	--	--	--	--	5
Renable Mines	1	--	1	--	--	--	--	--	--	--	2
Rio Algom Quirke	2	1	4	1	--	--	1	1	--	--	[illegible]
Sherritt Gordon (Fox)	2	--	5	1		--	1	1	--	--	11
Sherritt Gordon (Lynn)	2	1	7	2	2	2	3	3	1	--	23
Sigma Mines	--	--	--	-	1	--	--	--	--	2	3
Similkameen Mining	--	--	--	--	--	1	--	--	--	--	1
Siscoe Metals	1	--	--	--	--	1	--	--	--	--	2
St. Lawrence Columbium	1	1	3	2	--	2		--	--	-	[illegible]
Sullivan Mining (Cuprus)	1	--	4	--	--		--	1	[illegible]	-	[illegible]
Tantalum Mining	1	1	--	--	--	2	--	--	--	--	4
Te[illegible] Corp. - Beaverdell	--	1	--	--	--	1	--	--	--	--	2
Texada Mines	1	1	--	--	--	2	--	--	--	--	4
Texas Gulf (Kidd Creek)	2	1	7	7	2	--	[illegible]	--	--	--	21
Tribag Mining	2	-	--	--	--	2	--	--	--	--	4
Upper Canada and [illegible]	1	--	--	--	1	1	--	1	--	--	4
Venus Mines	1	1	--	--	--	1	--	--	2	--	5
Wesfrob Mines	1	7	--	2	--	1	[illegible]	--	1	--	13
[illegible] Iron Mines	1	1	--	1	--	2	1	1	--	--	7
Zenmac Metal	1	--	--	--	--	--	--	--	--	--	1
	105	116	242	77	31	115	60	87	68	15	916

MILL FORCE

TABLE D

Hourly Rated

	Grinding, operators, helpers	Crusher operators, helpers	Flotation operators, helpers	Conveyor operators	Filter operators	Solution men	Tailings disposal	Drying	Sampling	Assaying	Gen'l. operators, helpers, labor	Mechanical maintenance	Electrical Maintenance	Amalgamators	Roaster operator, helper	Utility	Backfill plant	Reagent men	Other	Other	TOTAL CREW	TOTAL EMPLOYEES IN DEPT.
Advocate Mines	--	[illegible]	--	--	--	--	4	4	--	--	12	27	4	--	--	--	--	--	--	--	[illegible]	[illegible]
Amico Mines	3	5	4	--	1	--	--	1	--	--	--	2	--	--	--	--	--	--	--	--	16	[illegible]
Algoma Ore	--	--	[illegible]	4	[illegible]	--	5	--	[illegible]	1	[illegible]	--	--	--	--	--	--	--	--	[illegible]	18	[illegible]
Anglo-Rouyn Mines	4	4	4	--	4	--	--	--	--	1	--	1	--	--	--	--	--	--	--	1	[illegible]	[illegible]
Auger Gold Mines		8	4	--	--	--	--	--	--	--	4	2	--	--	--	--	--	--	--	--	[illegible]	[illegible]
Bethlehem Copper	4	12	4	--	4	--	--	4	7	4	--	9	4	--	--	1	--	2	1	--	[illegible]	[illegible]
Bralorne Can-Fer	4	1	--	--	--	4	--	1	--	1	--	--	--	--	--	--	--	--	--	--	10	11
Brenda Mines	4	16	5	--	4	--	14	--	4	8	--	--	--	--	--	--	--	1	4	--	[illegible]	[illegible]
British Columbia Molybdenum	5	12	4	--	1	--	--	1	1	--	--	14	--	--	--	--	--	1	2	--	44	[illegible]
Brunswick M. & S.	12	12	12	--	4	--	1	4	[illegible]	11	45	51	10	--	--	4	--	2	5	[illegible]	[illegible]	[illegible]
Camflo Mines	4	4	--	1	1	1	--	--	--	4	4	--	--	--	--	--	--	--	--	--	[illegible]	[illegible]
Canadian Expl. Tungsten	4	3	4	--	--	--	1	--	1	--	4	1	--	--	--	--	--	--	--	1	[illegible]	34
Canadian Jamieson	4	3	4	--	4	--	--	--	--	3	3	--	--	--	--	--	--	1	--	--	32	41
Cassiar Asbestos Clinton	--	8	--	--	--	--	1	--	--	--	[illegible]	--	--	--	--	--	--	--	--	--	41	[illegible]
Consol. Cdn. Faraday	4	4	4	4	--	--	--	--	--	1	8	--	--	--	--	--	--	--	--	--	[illegible]	[illegible]
Consol. Rambler	4	4	4	--	4	--	--	--	1	1	1	3	1	--	--	1	--	1	1	--	[illegible]	[illegible]
Craigmont Mines	4	12	4	8	4	--	--	--	4	--	10	4	1	--	--	--	--	--	--	--	[illegible]	44
Deer Horn Mines	3	2		--	1	--	--	--	--	--	1	1	--	--	--	--	--	--	--	1	12	[illegible]
Denison Mines	4	3	--	2	4	--	--	4	1	4	30	30	--	--	--	--	--	--	--	--	107	112
Dickenson Mines	3	3	--	--	--	4	--	--	--	3	1	3	--	1	4	--	1	--	1	--	31	[illegible]
Dresser Minerals	--	5	[illegible]	--	--	--	--	--	--	--	4	--	--	--	--	--	--	--	--	--	[illegible]	[illegible]
East Malartic	--	3	--	--	2	5	1	--	--	1	11	--	--	--	--	--	--	--	--	--	[illegible]	32
Echo Bay Mines	3	3	3	--	--	--	--	2	--	--	3	1	--	--	--	--	--	--	--	--	15	19
Eldorado Nuclear	3	3	3	--	8	--	--	--	1	--	9	--	--	--	--	--	--	1	7	8	[illegible]	[illegible]
Endako Mines	4	8	4	--	--	--	7	1	5	5	32	--	--	--	8	--	--	1	5	--	[illegible]	[illegible]
Gaspe Copper	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	[illegible]	84
Giant Mascot Mines	3	3	3	--	1	--	--	--	--	3	--	3	--	--	--	--	--	--	--	4	20	25
Giant Yellowknife	--	7	8	--	--	4	--	--	2	5	11	--	--	--	8	--	1	--	3	--	47	60
Granby Mining (Phoenix)	8	8	8	--	--	--	5	--	5	2	1	3	--	--	--	--	--	1	--	--	37	41
Granduc Operating	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2	2	8
Granisle Copper	4	12	4	--	4	--	--	--	--	4	2	10	--	--	--	--	--	--	--	--	40	50
Griffith Mine	8	8	8	4	4	--	4	--	4	--	30	63	13	--	--	--	--	--	--	--	144	191
Gullbridge Mines	4	5	4	1	--	--	--	--	--	2	3	5	--	--	--	--	--	--	--	--	28	36
Hollinger Mines	3	3	8	--	--	--	1	--	--	--	1	5	--	--	--	--	--	--	--	2	21	23
Heath Mines	3	5	8	--	4	1	--	--	--	11	4	--	--	--	--	--	--	--	--	--	39	52
Indusmin	2	4	--	--	--	--	--	1	--	3	16	5	2	--	--	--	--	--	--	--	36	42
Iron Ore Co. (Carol)	42	8	--	--	4	27	7	--	--	--	41	107	22	--	--	--	--	--	--	--	258	323
Iron Ore Co. (Schefferville)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Jones & Laughlin (Adams)	8	12	4	4	[illegible]	--	4	--	[illegible]	4	25	34	10	--	8	--	--	--	--	--	132	152
Jameland Mines	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Kam Kotia Mines	5	4	10	--	1	--	--	--	--	2	--	11	--	--	--	--	--	--	--	--	34	45
Kerr Addison	4	2	4	2	4	4	--	--	--	8	10	8	--	--	4	--	2	--	3	2	55	[illegible]
KRC Operators (Mt. Copeland)	4	1	4	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	1	1	12	18
Kidd Copper	6	4	3	--	--	--	--	--	--	1	--	2	1	--	--	--	--	--	--	--	[illegible]	[illegible]
Lake Asbestos	--	--	--	--	--	--	3		--	--	--	--	--	--	--	--	--	--	--	--	--	--
Lake Shore McLeod-Mosher	4	4	--	--	--	3	--	--	--	2	--	--	--	--	--	--	--	--	--	--	14	[illegible]
Lamaque Mining	8	6	--	--	--		--	--	--	--	2	7	--	--	--	3	--	--	1	1	[illegible]	[illegible]
Leitch Mastodon H. B.	4	--	4	--	--	--	--	--	--	--	2	1	--	--	--	--	--	--	--	--	11	[illegible]
Madeleine, Lee Mines	8	16	4	--	1	--	--	--	--	--	--	8	--	--	--	4	--	1	--	--	42	[illegible]
Madsen Red Lake	4	[illegible]	--	--	--	4	--	--	--	2	--	4	--	1	--	1	2	--	[illegible]	--	[illegible]	[illegible]
Malartic Gold Fields	5	[illegible]	--	--	--	4	--	--	4	4	2	11	--	--	--	--	--	--	--	--	[illegible]	[illegible]
Manitou Barvue	4	8	5	--	1	1	1	--	1	10	3	7	--	--	--	--	1	--	--	--	[illegible]	[illegible]
Mattagami Lake	3	8	4	--	2	--	1	2	2	8	9	11	3	--	--	--	1	1	--	--	[illegible]	[illegible]
McIntyre Porcupine	4	8	4	--	3	4	--	--	1	8	4	10	--	--	--	5	4	1	1	3	[illegible]	[illegible]
National Steel (Moose Mt.)	4	12	5	--	--	--	--	--	9	--	9	28	--	--	--	--	--	--	--	13	74	[illegible]
New Imperial	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	[illegible]	[illegible]
Nigadoo River	4	3	4	--	2	--	2	1	--	[illegible]	1	8	--	--	--	--	--	--	--	--	32	41
Noranda (Geco)	4	4	5	8	4	--	4	4	1	12	25	27	1	--	--	--	--	1	4	--	107	127
Noranda (Horne)	4	--	8	3	4	4	1	[illegible]	4	--	--	12	--	--	--	4	--	--	2	5	--	[illegible]
Normetal	4	4	5	--	4	--	--	[illegible]	--	4	4	4	--	--	--	--	2	2	1	1	42	55
Opemiska Copper	4	8	4	--	4	--	--	--	--	[illegible]	--	48	7	--	--	--	--	3	--	--	38	48
Orchan Mines	4	5	4	--	4	--	1	[illegible]	1	1	8	8	--	--	--	--	1	1	1	--	38	[illegible]
Pamour Porcupine	5	7	--	--	--	4	2	--	--	--	13	[illegible]	--	--	--	--	--	--	--	3	43	57
Pickands Mather Hilton	[illegible]	12	--	--	--	--	3	[illegible]	[illegible]	4	12	--	--	--	--	--	--	--	1	3	[illegible]	[illegible]
Preissac Molybdenite	4	--	5	4	--	8	2	--	--	--	3	[illegible]	--	--	3	--	2	1	1	--	39	40
Quemont Mines	--	--	3	--	1	--	--	--	2	3	3	5	--	--	--	1	[illegible]	2	4	1	[illegible]	52
Red Mountain Mines	4	3	4	--	--	--	--	--	--	1	--	--	--	--	--	--	--	1	--	--	14	19
Reeves MacDonald	3	3	3	--	--	--	--	--	1	--	--	1	--	--	--	--	--	--	--	1	12	17
Renable Mines	3	2	--	--	--	4	1	--	[illegible]	2	3	2	--	--	--	1	--	--	--	--	14	[illegible]
Rio Algom Quirke	4	4	--	1	4	4	4	[illegible]	1	5	4	27	1	--	--	--	1	4	4	[illegible]	[illegible]	[illegible]
Sherritt Gordon (Fox)	--	4	8	--	4	--	--	--	--	--	8	[illegible]	1	--	--	--	--	--	1	1	14	[illegible]
Sherritt Gordon (Lynn)	4	12	4	--	3	--	2		4	10	10	15	--	--	--	--	--	2	4		[illegible]	[illegible]
Sigma Mines	1	3	--	1	--	--	--		--	--	[illegible]	--	--	--	--	--	--	--		--	11	[illegible]
Similkameen Mining	--	--	--	--	--	--	--	--	[illegible]	--	--	--	--	--	--	--	--	--	--	--	[illegible]	[illegible]
Siscoe Metals	3	1	3	--	--	--	--	--	--	--	[illegible]	1	--	--	--	--	--	--	--		11	[illegible]
St. Lawrence Columbium	5	8	8	--	--	--		--	--	4	--	3	--	--	--	--	--	--	1	1	31	40
Sullivan Mining (Cupra)	4	8	4	--	3	--	--	4	--	4	3	4	--	--	--	--	--	--	--	1	[illegible]	[illegible]
Tantalum Mining	4	1	--	--	--	--	--	--	2	--	--	2	--	--	--	--	--	--	--	--	1	[illegible]
Teck Corp. - Beaverdell	4	--	4	--	--	--	--	--	--	--	2	1	--	--	--	--	--	--	--	--	11	13
[illegible] Mines	8	3	3	--	--	--	--	[illegible]	1	1	2	8	--	--	--	2	--	--	4	--	11	15
Texas Gulf (Kidd Creek)	12	16	12	--	2	--	[illegible]		11	[illegible]	41	--	--	--	--	--	--	4	4	--	132	154
Tribag Mining	3	[illegible]	3	--	--	--	--	--	--	--	--	4	--	--	--	--	--	--	--	--	21	25
Upper Canada and Beaver	4	4	4	--	--	4	--	--	3	3	--	2	--	--	--	--	--	--	--	1	35	39
Venus Mines	3	2	3	--	1	--	2	--		1	2	--	--	--	--	--	--	--	--	--	19	24
Wesfrob Mines	8	14	3	8	3	--	--	--		3	14	--	--	--	--	--	--	--	--	3	52	65
Willroy Mines	4	4	4	--	4	--	--	--	--	3	3	--	--	--	--	--	--	--		--	20	33
Zenmac Metal	[illegible]	1	[illegible]	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	5	[illegible]
	403	469	318	51	131	106	95	105	124	223	719	714	81	2	36	28	25	36	76	74	3,818	4,739

PLANT FORCE REPORT (Mechanical, Electrical, Surface) Staff

TABLE D

	Plant superintendent	Master mechanic	Chief electrician	Surface superintendent	Foremen, shops, maint.	Engineers	Secretary, clerks	Warehousemen	Construction supervisor	Other	Other	TOTAL STAFF
Advocate Mines	--	--	1	1	6	4	--	--	--	2	7	21
Agnico Mines	--	1	1	--	--	--	--	--	--	--	--	2
Algoma Ore	2	1	1	--	12	3	6	--	2	--	--	27
Anglo-Rouyn Mines	1	1	1	1	2	--	--	--	--	--	--	6
Aunor Gold Mines	1	--	1	--	2	--	--	2	1	--	--	7
Bethlehem Copper	2	1	3	1	3	4	2	5	1	--	--	22
Bralorne Can-Fer	--	1	1	1	1	--	--	--	--	--	--	4
Brenda Mines	1	1	1	1	9	5	2	--	--	--	--	17
British Columbia Molybdenum	1	2	1	1	7	1	2	--	1	10	--	26
Brunswick M. & S.	2	1	--	--	28	15	3	--	1	1	--	51
Camflo Mines	--	--	1	--	1	--	--	--	--	--	--	2
Canadian Expl. Tungsten	--	1	--	--	3	1	--	--	--	--	--	5
Canadian Jamieson	--	1	--	--	1	--	--	--	--	--	--	2
Cassiar Asbestos Clinton	1	1	1	1	14	1	1	1	--	5	--	26
Consol. Cdn. Faraday	1	--	1	--	1	--	--	--	--	--	--	3
Consol. Rambler	--	1	1	1	2	--	--	--	--	--	--	5
Craigmont Mines	1	1	1	--	8	1	2	--	--	4	--	18
Deer Horn Mines	--	--	--	--	--	--	--	--	--	--	--	--
Denison Mines	--	1	1	1	4	3	[illegible]	--	--	--	--	10
Dickenson Mines	--	1	1	1	1	--	--	--	--	--	--	4
Dresser Minerals	--	--	--	--	1	--	--	--	--	--	--	1
East Malartic	1	1	1	1	4	--	--	--	--	--	--	8
Echo Bay Mines	--	--	1	1	1	--	1	2	--	--	--	6
Eldorado Nuclear	1	1	1	--	9	--	1	--	1	2	2	17
Endako Mines	2	2	2	--	15	4	3	--	--	--	--	32
Gaspe Copper	1	3	1	--	36	1	6	16	--	10	2	76
Giant Mascot Mines	--	1	--	1	--	--	--	--	--	--	--	2
Giant Yellowknife	1	--	1	--	7	--	--	--	1	--	--	10
Granby Mining (Phoenix)	--	1	1	1	1	--	1	--	--	--	--	4
Granduc Operating	2	1	1	--	6	2	3	1	--	5	3	24
Granisle Copper	1	1	1	1	2	--	--	--	--	--	--	6
Griffith Mine	1	--	1	2	10	3	--	--	--	7	6	30
Gullbridge Mines	--	--	--	--	--	--	--	--	--	--	--	--
Hallnor Mines	1	--	1	--	1	--	--	--	--	--	--	3
Heath Mines	1	1	1	1	1	--	1	--	--	--	--	6
Indusmin	1	1	1	--	--	--	--	--	--	--	--	3
Iron Ore Co. (Carol)	1	3	1	1	36	6	11	--	--	--	..	59
Iron Ore Co. (Schefferville)	1	1	1	--	54	6	4	2	1	1	1	72
Jones & Laughlin (Adams)	--	1	1	--	6	1	1	6	--	1	..	18
Jameland Mines	--	--	--	--	--	--	--	--	--	--	..	--
Kam Kotia Mines	1	--	1	--	2	--	--	2	--	--	..	4
Kerr Addison	--	1	1	1	3	--	--	--	--	--	--	6
KRC Operators (Mt. Copeland)	1	--	--	--	--	--	--	--	--	--	..	1
Kidd Copper	1	--	--	--	--	--	1	--	--	--	..	2
Lake Asbestos	1	2	1	1	4	2	2	3	--	--	..	16
Lake Shore McLeod-Mosher	1	--	1	5	1	--	--	2	--	--	..	10
Lamaque Mining	1	2	2	--	3	1	--	--	1	--	..	10
Leitch Mastodon H. B.	--	1	1	--	--	--	--	1	--	--	..	3
Madeleine, Les Mines	1	1	1	1	5	--	--	--	--	--	..	9
Madsen Red Lake	--	1	1	1	3	--	--	3	--	1	..	10
Malartic Gold Fields	--	--	--	--	--	--	--	--	--	--	..	--
Manitou Barvue	1	1	1	4	--	1	1	1	1	--	..	11
Mattagami Lake	1	1	1	--	4	2	1	--	--	1	..	10
McIntyre Porcupine	1	1	1	--	3	1	1	1	--	1	1	10
National Steel (Mouse Mt.)	1	1	1	5	3	1	1	--	--	1	..	14
New Imperial	1	--	1	--	2	--	1	--	--	--	..	5
Nigadoo River	1	--	1	4	--	--	1	1	1	--	..	[illegible]
Noranda (Geco)	1	1	1	--	13	4	1	4	--	2	..	27
Noranda (Horne)	1	1	1	1	20	11	5	10	4	2	7	63
Normetal	--	1	1	--	5	--	--	--	--	1	1	9
Opemiska Copper	2	1	1	--	5	--	1	--	--	1	1	12
Orchan Mines	2	1	1	--	5	--	1	--	--	--	--	10
Pamour Porcupine	1	1	1	--	3	1	--	--	--	--	--	7
Pickands Mather Hilton	1	2	1	1	7	1	4	--	--	1	1	19
Preissac Molybdenite	--	1	1	--	1	--	--	--	--	--	--	3
Quemont Mines	1	1	1	1	7	--	--	--	--	--	--	11
Red Mountain Mines	--	1	--	--	--	--	--	--	--	--	..	1
Reeves MacDonald	1	1	--	1	--	--	--	--	--	--	..	3
Renabie Mines	--	1	1	1	--	--	--	--	--	--	..	3
Rio Algom Quirke	1	1	1	--	15	[illegible]	1	--	--	--	..	27
Sherritt Gordon (Fox)	--	--	--	--	[illegible]	[illegible]	1	[illegible]	--	--	..	5
Sherritt Gordon (Lynn)	1	1	1	--	11	5	3	--	--	--	..	24
Sigma Mines	1	1	1		3	--	--	[illegible]	--	--	..	9
Similkameen Mining	--	1	1	--	[illegible]	7	1	[illegible]	--	--	1	18
Siscoe Metals	--	1	--	--	--	--	--	--	--	--	..	1
St. Lawrence Columbium	--	1	1	--	--	--	--	--	--		..	2
Sullivan Mining (Cupra)	--	1	1	--	3	--	--	--	--	--	..	[illegible]
Tantalum Mining	1	1	1	1	--	--	--	--	--	--	1	5
Teck Corp. - Beaverdell	--	1	--	--	--	--	--	--	--	--	..	1
Texada Mines	1	1	2	1	--	1	--	6	--	--	..	12
Texas Gulf (Kidd Creek)	1	4	1	1	21	4	6	--	3	[illegible]	..	41
Tribag Mines	--	1	1	1	1	--	--	--	--	--	..	4
Upper Canada and Beaver	--	1	1	1	--	--	--	--	--	--	..	3
Venus Mines	--	--	1	--	--	--	--	--	--	--	..	1
Wesfrob Mines	1	1	1	--	5	1	1	3	--	--	..	13
Willroy Mines	2	1	1	--	--	--	--	--	--	--	..	4
Zenmac Metal	--	1	1	--	--	--	--	--	--	--	..	2
	61	77	75	52	673	120	92	73	19	67	34	1,163

PLANT FORCE REPORT

TABLE D

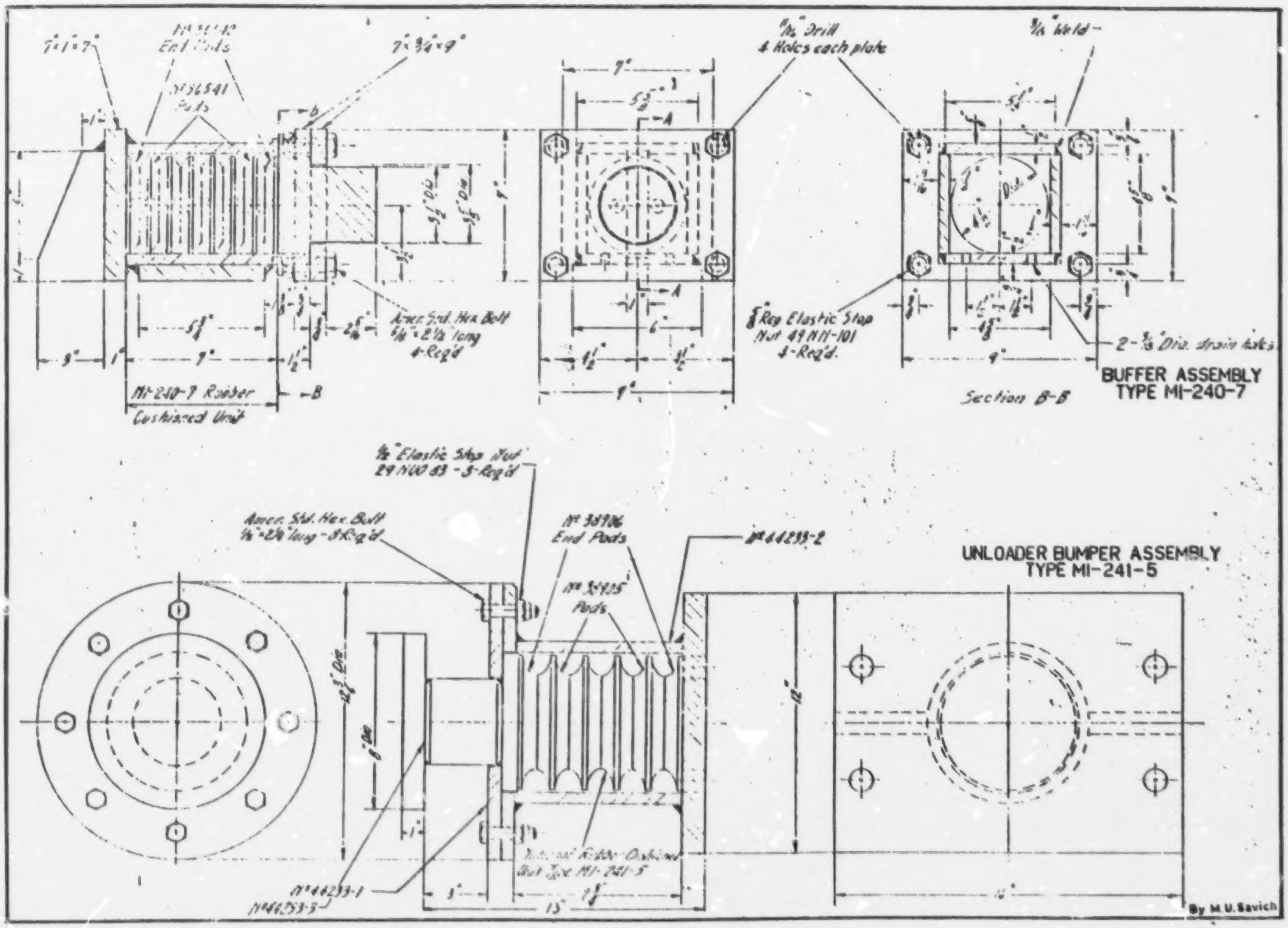
Hourly Rated

	Powerhouse, steam plant	Machine shop, tradesmen	Mechanics, helpers	Welders, helpers	Blacksmiths	Riggers	Pipefitters, plumbers	Drill steel, bits	Drill repair	Plate shop	Vulcanizing	Electricians	Carpenters	Painters	Construction workers	Mobile equipment operators	Hoistmen	Compressormen	Labourers	Other	TOTAL PLANT CREW	TOTAL SURFACE PLANT
Advocate Mines	--	2	42	10	--	--	--	--	--	--	--	11	5	--	--	--	--	--	--	7	133	134
Agnico Mines	--	--	2	1	--	--	--	1	1	--	--	2	2	--	--	4	--	--	--	--	13	15
Algoma Ore	--	7	41	10	2	2	1	--	1	--	2	10	1	--	--	26	--	--	21	1	153	157
Anglo-Rouyn Mines	3	5	5	4	--	--	1	1	1	--	--	5	4	--	--	2	1	--	2	--	16	23
Aunor Gold Mines	7	1	4	8	--	--	--	--	--	--	--	8	4	--	--	1	11	--	1	--	42	52
Bethlehem Copper	--	1	11	8	--	--	7	--	--	--	1	6	1	1	--	4	--	--	2	--	40	59
[illegible] Can-Fer	5	2	1	1	1	--	1	--	--	--	--	1	1	--	1	2	--	--	1	--	17	21
Brenda Mines	5	2	11	10	--	--	2	--	--	--	--	20	4	--	--	--	--	--	10	1	104	[illegible]
British Columbia Molybdenum	--	2	57	5	--	--	1	1	--	--	--	11	2	--	--	5	--	1	1	1	70	[illegible]
Brunswick M. & S.	5	8	51	29	1	--	15	--	1	--	4	21	11	3	--	18	--	--	20	--	193	244
Camflo Mines	--	1	7	2	--	--	--	--	--	--	--	4	2	--	--	1	4	--	1	--	22	24
Canadian Expl. Tungsten	--	4	8	2	--	--	1	--	1	--	--	--	1	--	4	3	--	4	3	2	39	44
Canadian Jamieson	--	--	4	2	1	--	--	1	--	--	--	2	--	--	--	--	4	--	4	2	20	22
Cassiar Asbestos Clinton	8	2	16	11	--	--	1	5	1	--	--	10	1	1	--	22	8	--	8	8	127	[illegible]
Consol. Cdn. Faraday	--	15	--	--	--	--	1	--	1	--	--	2	2	--	--	1	2	--	--	--	24	27
Consol. Rambler	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Craigmont Mines	4	8	70	14	2	--	1	--	2	--	--	18	4	2	--	15	--	--	5	--	150	190
Deer Horn Mines	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Denison Mines	13	10	33	11	2	1	3	--	1	10	4	21	10	2	--	15	18	--	1	--	153	172
Dickenson Mines	--	1	[illegible]	4	2	--	2	--	--	--	--	4	2	--	--	4	5	4	5	1	36	50
Dresser Minerals	--	1	7	2	--	--	--	--	--	--	--	2	3	1	--	--	--	--	--	--	10	17
East Malartic	--	5	5	--	1	--	--	2	1	--	--	5	1	--	--	11	7	3	--	7	47	57
Echo Bay Mines	5	--	4	1	--	--	2	--	--	--	--	5	2	1	--	6	--	--	4	--	31	37
Eldorado Nuclear	12	42	--	--	1	--	1	--	--	4	2	18	[illegible]	--	--	2	--	--	2	--	47	104
Endako Mines	--	25	[illegible]	25	--	2	--	--	--	--	2	15	10	2	--	7	--	--	5	--	150	182
Gaspe Copper	25	12	112	31		12	6	3	--	12	2	29	18	1	--	19	--	--	--	3	[illegible]	[illegible]
Giant Mascot Mines	--	6	1	[illegible]	1	--	--	1	1	--	--	3	2	--	--	4	--	--	--	--	22	23
Giant Yellowknife	4	4	7	3	1	--	4	--	--	--	--	7	15	--	--	1	--	--	--	--	45	44
Granby Mining (Phoenix)	--	5	[illegible]	3	--	--	--	1	--	--	--	4	3	1	--	4	--	--	1	--	14	24
Granduc Operating	10	13	10	4	--	--	--	--	--	--	--	9	3	--	--	10	--	--	19	5	103	127
Granisle Copper	--	1	15	3	--	--	--	--	--	--	--	4	3	--	--	5	--	--	7	--	36	44
Griffith Mine	--	2	33	15	--	--	--	--	--	--	--	7	2	2	--	76	--	4	27	10	157	217
Gullbridge Mines	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Hallnor Mines	--	3	3	1	--	--	--	--	--	--	--	1	--	--	--	--	6	--	4	--	18	21
Heath Mines	4	1	28	11	2	--	--	--	--	--	--	12	2	--	--	17	--	--	24	4	105	111
Indusmin	--	3	5	4	--	--	--	--	--	5	--	--	2	--	--	2	--	--	--	--	21	29
Iron Ore Co. (Carol)	12	18	91	48	--	--	13	--	--	--	4	41	18	7	--	6	--	--	23	--	251	310
Iron Ore Co. (Schefferville)	9	15	116	33	3	--	6	--	--	--	2	29	34	6	--	13	--	--	41	16	317	[illegible]
Jones & Laughlin (Adams)	6	57	15	--	--	--	--	--	--	--	--	5	--	2	--	9	--	4	5	3	112	130
Jameland Mines	--	--	----	--	--	--	--	--	2	--	--	--	--	--	--	--	2	4	--	--	[illegible]	9
Kam Kotia Mines	4	2	[illegible]	2	1	2	1	2	5	7	--	11	2	--	--	7	4	--	10	2	70	74
Kerr Addison	4	2	12	3	2	--	3	2	2	1	--	13	9	2	--	11	8	--	3	7	84	[illegible]
KRC Operators (Mt. Copeland)	4	--	1	1	--	--	--	--	--	--	--	2	1	--	--	5	--	--	2	6	22	25
Kidd Copper	6	4	1	--	--	--	--	--	--	1	--	2	1	--	--	--	--	--	--	--	17	19
Lake Asbestos	3	15	72	12	--	--	2	1	2	15	--	9	4	--	--	--	--	--	15	--	155	174
Lake Shore McLeod-Mosher	4	--	11	1	1	--	1	--	--	--	--	6	1	--	--	--	--	--	--	--	25	35
Lamaque Mining	--	6	4	4	1	--	1	1	2	--	--	7	8	--	--	3	7	4	12	--	60	70
Leitch Mastodon H.B.	--	2	----	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	2	--	5	5
Madeleine, Les Mines	--	5	3	3	--	--	2	1	1	--	--	4	2	--	3	6	--	1	6	--	44	50
Madsen Red Lake	--	1	5	4	1	--	3	--	--	--	--	4	6	--	--	1	3	3	3	2	37	47
Malartic Gold Fields	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Manitou Barvue	6	4	[illegible]	--	1	1	1	--	10	3	7	--	--	--	--	3	--	--	--	--	42	53
Mattagami Lake	4	3	56	11	1	--	4	--	2	2	--	14	3	2	--	--	3	--	7	--	112	125
McIntyre Porcupine	--	6	5	1	3	20	3	2	--	4	1	16	5	2	--	4	19	5	11	4	109	125
National Steel (Moose Mt.)	--	4	21	6	--	--	--	--	--	--	--	16	2	1	--	--	--	--	--	--	49	63
New Imperial	--	--	17	5	--	--	--	1	2	--	--	7	--	--	--	1	--	--	1	1	35	43
Nigadoo River	3	4	4	--	2	--	2	1	--	[illegible]	1	6	--	--	--	--	--	--	--	--	32	41
Noranda (Geco)	7	27	[illegible]	10	2	--	--	--	--	--	--	25	7	4	--	4	3	1	18	5	147	154
Noranda (Horne)	25	15	17	16	11	21	20	2	3	16	--	44	18	6	15	12	20	--	11	--	274	337
Normetal	7	--	5	7	1	--	3	1	1	1	--	7	7	--	--	4	4	--	10	7	66	73
Opemiska Copper	1	2	11	6	1	--	2	--	1	--	--	9	8	1	--	10	14	1	13	3	[illegible]	75
Orchan Mines	2	5	5	2	1	--	2	1	1	--	--	6	2	--	--	1	4	--	10	--	42	52
Pamour Porcupine	--	4	15	1	2	--	2	4	1	--	--	5	5	1	--	2	5	--	4	--	54	63
Pickands Mather Hilton	5	6	61	13	--	--	--	3	--	--	--	17	1	2	1	4	--	--	6	--	121	134
Preissac Molybdenite	--	--	5	1	2	--	1	3	1	--	--	6	4	--	--	--	--	--	3	4	[illegible]	[illegible]
Quemont Mines	4	5	--	--	1	--	1	1	1	2	--	19	2	1	--	5	6	--	5	--	47	58
Red Mountain Mines	--	3	--	--	--	--	--	--	--	--	--	--	--	--	--	5	--	--	1	--	9	10
Reeves MacDonald	--	1	--	2	1	--	1	1	--	--	11	4	1	--	--	2	--	4	3	--	31	34
Renable Mines	--	1	6	3	1	--	--	--	--	--	--	4	3	1	--	2	12	--	--	1	36	37
Rio Algom Quirke	10	6	57	7	2	5	8	1	4	--	--	11	12	--	--	11	3	--	5	--	137	164
Sherritt Gordon (Fox)	4	3	25	4	--	--	1	--	--	--	--	12	2	--	--	3	4	--	5	--	63	71
Sherritt Gordon (Lynn)	4	10	21	5	2	--	5	--	--	--	--	24	10	1	--	6	15	4	15	--	167	191
Sigma Mines	5	2	5	1	1	2	2	2	2	--	--	2	2	1	--	5	6	--	14	4	[illegible]	[illegible]
Similkameen Mining	3	--	20	3	--	--	1	--	--	--	--	1	1	--	--	1	--	--	2	--	42	60
Siscoe Metals	--	--	2	1	--	--	--	--	1	--	--	1	1	--	--	--	--	--	--	--	6	7
St. Lawrence Columbium	--	3	6	4	1	--	1	--	--	--	--	3	3	--	--	1	--	--	--	--	[illegible]	24
Sullivan Mining (Cupra)	--	5	5	1	1	--	1	--	1	--	--	[illegible]	3	--	--	14	5	4	2	--	[illegible]	63
Tantalum Mines	--	1	5	2	1	--	1	--	1	--	--	1	2	--	--	2	--	--	2	--	[illegible]	27
Teck Corp. - Beaverdell	--	--	[illegible]	[illegible]	--	--	--	--	--	--	--	--	--	--	--	[illegible]	--	--	2	--		--
Texada Mines	--	1	27	2	1	--	--	1	--	--	--	[illegible]	1	--	--	3	3	--	13	1	61	[illegible]
Texas Gulf (Kidd Creek)	--	6	72	8	1	53	6	--	1	--	4	30	2	2	25	10	--	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Tribag Mines	--	--	7	2	2	--	--	--	1	--	--	1	1	--	--	[illegible]	4	1	[illegible]	--	[illegible]	[illegible]
Upper Canada and Beaver	--	--	15	--	1	--	--	2	1	--	--	[illegible]	2	1	--	--	10	--	21	--	[illegible]	52
Venus Mines	--	1	--	--	--	--	--	--	--	--	--	--	[illegible]	--	--	--	--	--	--	--	[illegible]	[illegible]
Wesfrob Mines	--	2	37	5	--	--	1	1	2	--	1	--	[illegible]	1	--	[illegible]	--	--	--	--	70	43
Willroy Mines	--	4	[illegible]	3	1	--	1	2	1	--	--	[illegible]	7	--	--	3	--	[illegible]	[illegible]	[illegible]	41	47
Zenmac Metal	1	--	--	--	1	--	--	--	--	--	--	--	[illegible]	--	--	1	[illegible]	--	--	--	4	5
	266	483	1,641	530	72	122	156	52	69	42	39	753	352	61	49	181	248	96	544	143	6,241	7,384

FORCE REPORT (Offices, General)

TABLE D

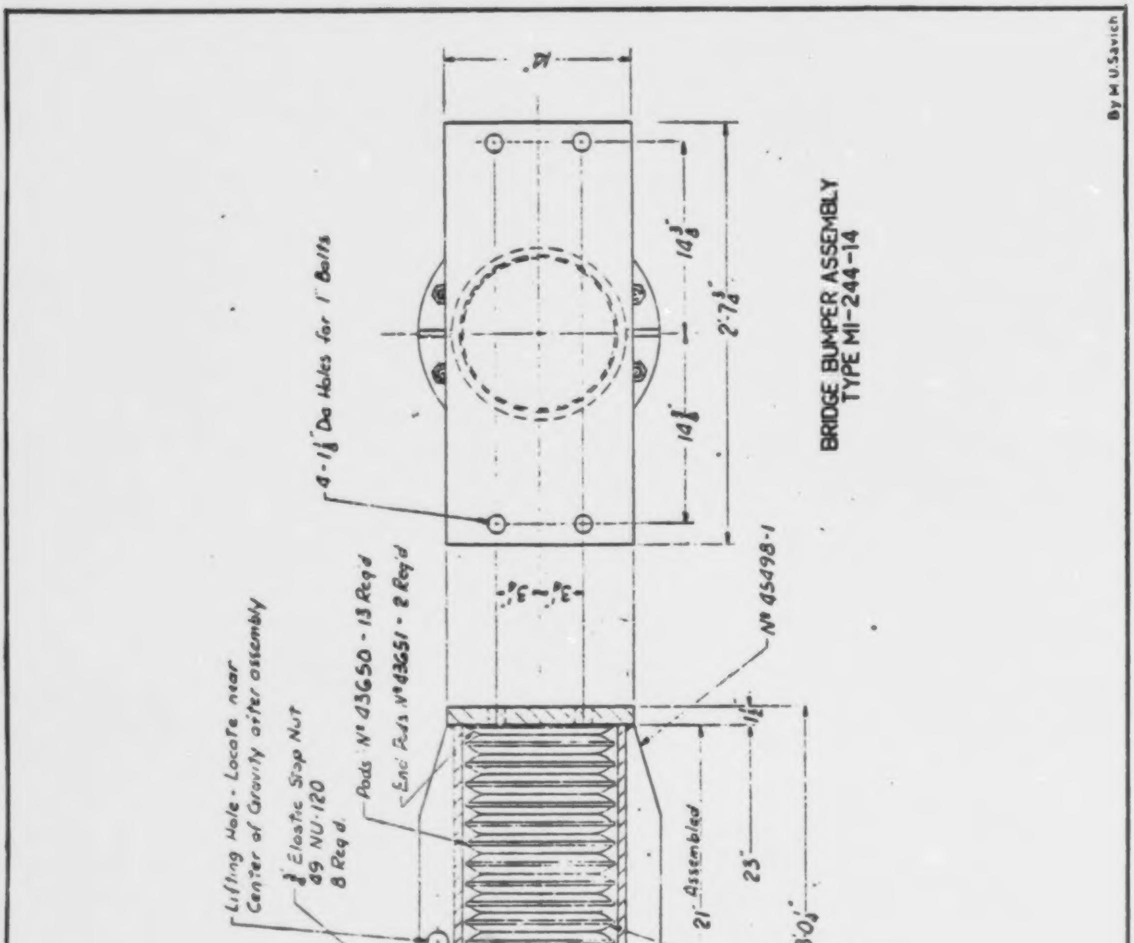
	Staff									Hourly Rated									
	Engineering	Geological	Office Managers	Accounting	Purchasing	Warehouse	Security	Personnel	First Aid, Safety	Secretarial, receptionist	Drymen	Janitors	Watchmen	Gardeners	Clerks	Other	Other	Other	Other	TOTAL
Advocate Mines	12	1	1	5	3	11	5	2	1	3	--	1	--	--	--	5	--	--	--	51
Agnico Mines	--	--	--	2	1	--	--	--	--	1	--	--	3	--	--	--	--	--	--	7
Algoma Ore	22	2	1	10	4	12	13	6	2	2	1	3	2	1	--	--	--	--	--	89
Anglo-Rouyn Mines	--	2	1	4	5	--	2	2	2	1	1	--	--	--	--	--	--	--	--	20
Aunor Gold Mines	3	2	--	3	1	1	5	--	2	1	--	--	--	--	--	--	--	--	--	18
Bethlehem Copper	6	2	1	4	1	4	1	1	1	2	--	2	--	2	4	2	2	--	--	35
Bralorne Can-Fer	2	--	--	1	1	1	--	--	1	2	1	2	2	--	--	--	--	--	--	13
Brenda Mines	9	1	1	4	3	4	--	1	8	4	1	4	--	--	5	--	--	--	--	45
British Columbia Molybdenum	5	1	1	1	2	5	1	4	2	2	4	3	--	--	5	--	--	--	--	36
Brunswick M. & S.	--	--	--	15	6	13	13	4	4	2	--	--	--	--	--	14	--	--	--	77
Camflo Mines	4	2	--	3	1	--	--	--	--	--	1	--	--	--	--	--	--	--	--	11
Canadian Expl. Tungsten	8	1	--	4	--	3	2	1	2	1	1	1	--	--	--	--	--	--	--	24
Canadian Jamieson	2	2	1	3	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	9
Cassiar Asbestos Clinton	3	2	1	3	2	5	--	4	7	2	--	7	1	--	--	2	7	3	22	87
Consol. Cdn. Faraday	2	2	1	1	1	1	--	--	1	1	--	--	--	2	--	--	--	--	--	12
Consol. Rambler	4	1	--	4	1	2	2	1	--	1	--	1	--	--	--	2	--	--	--	15
Craigmont Mines	15	8	1	4	1	3	4	4	5	4	2	2	--	--	--	--	--	--	--	53
Deer Horn Mines	1	--	--	1	--	--	--	--	--	1	--	--	1	--	--	--	--	--	--	4
Denison Mines	27	7	1	21	8	12	8	4	9	1	6	3	1	--	--	--	--	--	--	103
Dickenson Mines	--	--	1	3	1	2	--	1	--	2	1	--	--	--	--	5	1	1	--	18
Dresser Minerals	2	1	1	3	1	1	--	--	1	1	--	--	--	--	--	--	--	--	--	11
East Malartic	5	2	--	7	1	2	1	1	--	1	--	--	--	--	--	1	--	--	--	21
Echo Bay Mines	1	1	--	1	--	1	1	--	2	--	--	2	--	--	--	8	--	--	--	17
Eldorado Nuclear	1	5	--	8	5	14	--	9	2	15	--	1	2	--	--	7	1	1	1	64
Endako Mines	18	5	--	10	--	16	5	3	1	2	--	--	--	--	--	10	102	--	--	172
Gaspe Copper	21	8	--	19	2	23	17	7	2	--	--	2	--	--	--	--	--	--	--	94
Giant Mascot Mines	5	2	1	1	--	1	--	--	3	1	--	--	1	--	--	--	--	--	--	15
Giant Yellowknife	--	--	1	4	2	6	--	2	--	2	1	--	3	--	4	--	--	--	--	25
Granby Mining (Phoenix)	--	3	9	1	1	--	3	--	1	2	--	1	--	--	--	--	--	--	--	17
Granduc Operating	27	4	--	4	--	15	--	2	6	3	3	2	1	--	3	1	--	--	--	71
Gransile Copper	6	3	--	3	--	2	--	--	1	2	--	2	--	1	--	--	--	--	--	20
Griffith Mine	7	--	1	3	5	14	--	3	2	7	--	2	--	--	6	--	--	--	--	50
Gullbridge Mines	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Hallnor Mines	2	1	--	--	--	1	--	--	1	--	2	1	--	--	--	--	--	--	--	6
Heath Mines	15	11	--	4	1	3	1	--	--	3	--	--	--	--	--	3	--	--	--	41
Indusmin	3	1	--	2	1	1	--	1	--	1	--	1	--	--	--	--	--	--	--	11
Iron Ore Co. (Carol)	90	--	2	41	--	74	--	[illegible]	12	--	--	42	--	--	--	67	--	--	--	330
Iron Ore Co. (Schefferville)	43	40	1	34	--	41	3	5	8	2	--	24	--	--	--	11	20	10	--	247
Jones & Laughlin (Adams)	6	--	--	3	2	--	5	1	1	1	6	--	--	--	13	2	1	1	1	42
Jameland Mines	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Kam Kotia Mines	5	3	1	3	1	2	--	--	1	1	2	1	--	--	--	--	--	--	--	23
Kerr Addison	11	2	1	4	1	6	1	2	2	3	--	--	3	--	--	3	2	3	--	44
KRC Operators (Mt. Copeland)	--	--	1	1	1	--	--	--	1	1	--	--	--	--	--	--	--	--	--	5
Kidd Copper	1	1	--	1	1	--	--	--	--	1	--	--	--	--	--	--	--	--	--	5
Lake Asbestos	3	1	1	2	2	2	1	3	--	4	--	2	--	--	6	--	--	--	--	27
Lake Shore McLeod-Mosher	2	--	1	2	--	1	--	1	--	1	--	1	--	--	1	--	--	--	--	13
Lamaque Mining	--	--	1	2	1	2	--	2	1	2	3	1	3	--	--	1	--	--	--	17
Leitch Mastodon H. S.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Madeleine, Les Mines	7	2	--		1	4	1	1	1	2	--	--	3	--	2	--	--	--	--	23
Madsen Red Lake	4	2	1	3	--	--	--	--	--	1	2	1	1	--	--	1	1	--	--	17
Malartic Gold Fields	1	3	--	3	1	1	1	1	1	--	3	1	--	4	--	--	--	--	--	15
Manitou Barvue	4	2	--	3	1	1	1	1	1	1	2	1	2	--	--	--	--	--	--	20
Mattagami Lake	22	4	1	3	1	6	8	3	4	2	2	--	--	--	--	--	--	--	--	60
McIntyre Porcupine	12	2	--	4	3	3	8	2	2	3	4	4	4	4	--	--	--	--	--	55
National Steel (Moose Mt.)	2	2	1	1	1	5	--	1	--	2	4	--	--	--	--	--	--	--	--	21
New Imperial	3	3	--	3	1	3	--	1	--	2	--	--	--	--	--	--	--	--	--	20
Nigadoo River	7	4	--	3	1	4	3	--	1	2	2	1	--	--	--	--	--	--	--	24
Noranda (Geco)	21	5	1	18	5	--	7	3	4	1	1	2	--	--	--	--	--	--	--	73
Noranda (Horne)	12	3	--	3	6	4	15	7	4	7	2	8	--	3	1	18	--	--	--	104
Normetal	--	--	1	2	1	2	--	--	1	2	--	2	--	--	3	2	2	--	--	20
Opemiska Copper	24	18	1	8	3	6	2	4	4	3	--	2	[illegible]	--	--	--	--	--	--	50
Orchan Mines	3	3	--	--	--	--	--	--	-	--	--	--	--	--	--	--	--	--	--	[illegible]
Pamour Porcupine	10	2	1	1	1	2	4	1	1	1	4	--	--	--	3	--	--	--	--	36
Pickands Mather Hilton	3	--	1	3	1	5	4	1	1	5	--	1	--	--	3	--	--	--	--	37
Preissac Molybdenite	--	--	--	--	--	--	--	--	-	--	--	--	--	--	--	--	--	--	--	--
Quemont Mines	4	3	1	4	6	1	1	1	5	1	1	1	3	--	5	--	--	--	--	32
Red Mountain Mines	1	--	--	1	1	--	--	--	-	1	--	1	--	--	--	--	--	--	--	[illegible]
Reeves MacDonald	3	3	1	2	1	--	--	--	-	--	--	--	--	--	--	--	--	--	--	9
Renable Mines	--	--	--	4	3	--	--	--	-	1	--	1	1	--	2	--	--	--	--	12
Rio Algom Quirke	4	--	1	28	3	15	15	2	-	5	--	--	--	--	8	3	2	--	--	59
Sherritt Gordon (Fox)	--	--	--	--	--	--	--	--	-	--	--	--	--	--	--	--	--	--	--	--
Sherritt Gordon (Lynn)	--	--	--	--	--	--	--	--	-	--	--	--	--	--	--	--	--	--	--	--
Sigma Mines	11	2	1	4	--	3	--	--	1	1	3	2	--	--	--	--	--	--	--	24
Similkameen Mining	2	--	1	3	1	--	4	--	1	3	--	2	--	--	--	1	--	--	--	16
Siscoe Metals	--	--	--	3	1	--	--	--	-	--	--	1	--	--	--	4	1	--	--	4
St. Lawrence Columbium	4	1	1	5	1	1	--	--	-	1	--	--	3	--	--	--	--	--	--	17
Sullivan Mining (Cupra)	7	3	1	7	1	4	1	1	1	1	--	--	--	--	1	--	--	--	--	30
Tantalum Mining		3	1	1	1	--	--	--	1	1	1	1	--	1	--	--	--	--	--	13
Teck Corp. Beaverdell		--	--		--	1	--	--	-	--	-	--	--	--	--	--	--	--	--	4
Texada Mines	[illegible]	1	1	1	1	1	--	--	-	2	--	--	--	--	1	--	--	--	--	12
Texas Gulf (Kidd Creek)	--	[illegible]	1	[illegible]	14	20	17	-		[illegible]	--	1	--	--	--	--	[illegible]	--	--	183
Tribag Mining	3		1	[illegible]	1	4	--	--	1	--	[illegible]	1	--	--	--	[illegible]	--	--	--	17
Upper Canada and Beaver	5	2	1	3	1	1	--	--	1	1	1	--	4	1	3	--	--	--	--	20
Venus Mines	1	1	1	3	--	--	--	[illegible]	-	--	--	--	--	--	--	-	--	--	--	5
Westfrob Mines	5	2	1	5	--	2	--	--	1	1	--	--	--	--	--	--	--	--	--	23
Willroy Mines	7	2	1	2	1	2	4	--	1	2	--	1	--	--	--	1	6	--	--	29
Zenmac Metal	--	-	--	--	--	--	--	--	-	--	--	--	--	--	--	--	--	--	--	--
	588	216	54	436	132	429	189	127	38	163	76	147	45	19	79	175	154	19	24	3310



BUFFER ASSEMBLY
TYPE MI-240-7

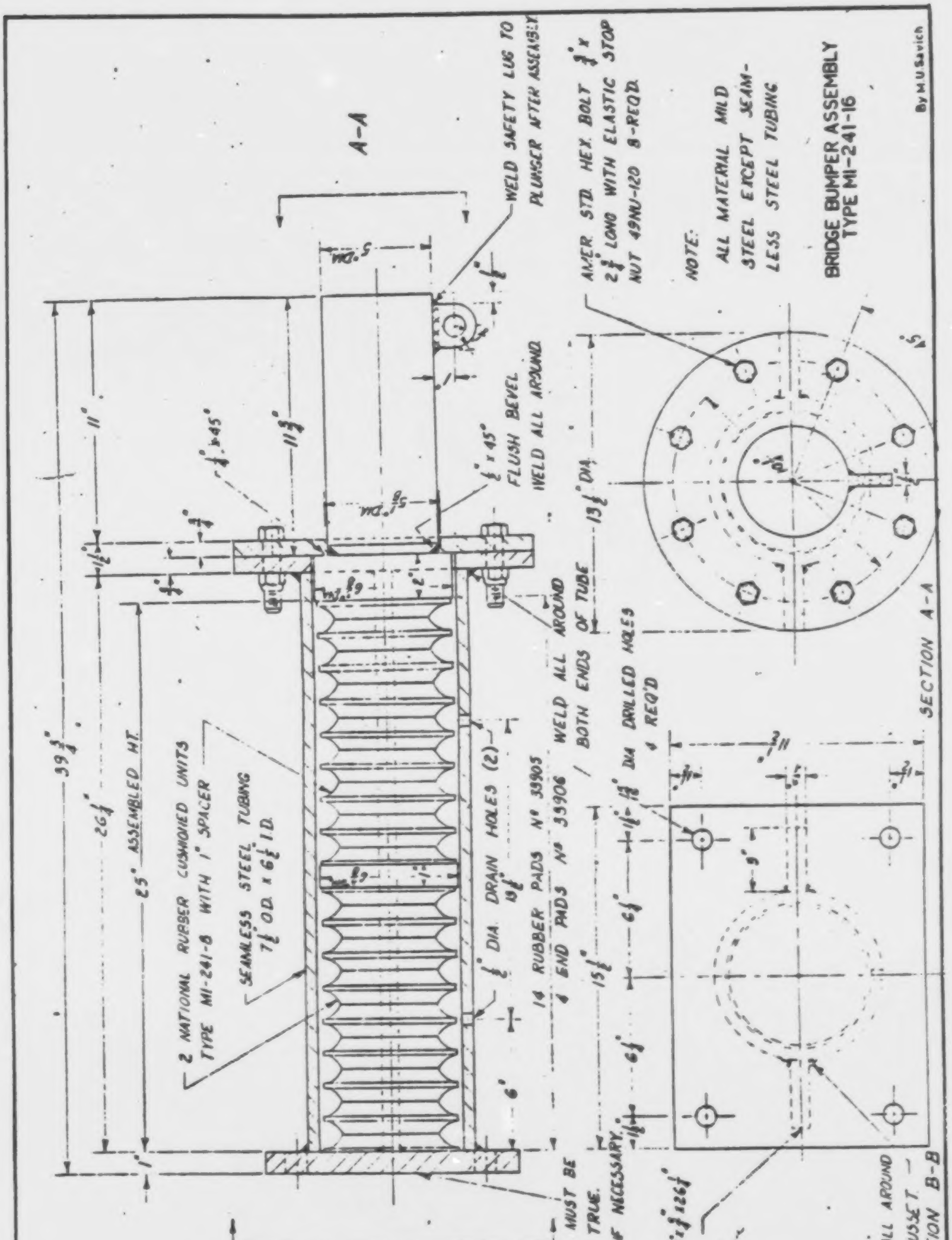
UNLOADER BUMPER ASSEMBLY
TYPE MI-241-5

7"×1"×7"
Nº 36542 End Pads
Nº 36541 Pads
7"×3/4"×9"
Amer. Std. Hex Bolt 5/16"×2 1/2" long 4-Req'd
MI-240-7 Rubber Cushioned Unit
Section B-B
9/16" Drill 4 Holes each plate
1/4" Weld
5/8" Reg Elastic Stop Nut 49 NM-101 4-Req'd.
2-3/8" Dia. drain holes
1/2" Elastic Stop Nut 29 NU0 83 - 8-Req'd
Amer. Std. Hex. Bolt 1/2"×2 1/4" long - 8-Req'd
Nº 38906 End Pads
Nº 38935 Pads
Nº 44233-2
Nº 44233-1
Nº 44233-3
Type MI-241-5
8" Dia
12 3/8" Dia.
15"
12"
9"
By M.U. Savich



BRIDGE BUMPER ASSEMBLY
TYPE MI-244-14

By M.U.Savich
12"
4 - 1 1/8" Dia Holes for 1" Bolts
14 1/8"
14 1/8"
2'-7 1/4"
3 1/2 - 3 1/2
No 45498-1
Pads No 43650 - 13 Req'd
End Pads No 43651 - 2 Req'd
Lifting Hole - Locate near Center of Gravity after assembly
3/4" Elastic Stop Nut 49 NU-120 8 Req'd
Safety Lug No 45498-4 Weld To Plunger after assembly
Amer. Std. Hex. Bolt 3/4" Dia. x 3 3/4 Lg 8 Req'd
1/2" - 2"
1 1/2"
21" Assembled
23"
3'-0 1/2"
2"
9 3/8"
National Rubber Cushioned Unit Type MI-244-14
18" Dia
No 45498-3
No 45498-2


A-A
WELD SAFETY LUG TO PLUNGER AFTER ASSEMBLY
AMER. STD. HEX. BOLT 3/4" x 2 3/4" LONG WITH ELASTIC STOP NUT 49NU-120 8-REQ'D.
NOTE:
ALL MATERIAL MILD STEEL EXCEPT SEAMLESS STEEL TUBING
BRIDGE BUMPER ASSEMBLY
TYPE MI-241-16
By M.U. Savich
5" DIA.
11"
11 3/4"
39 3/4"
26 1/2"
25" ASSEMBLED HT.
1/8" x 45°
3/8" x 45° FLUSH BEVEL WELD ALL AROUND
13 1/2" DIA.
WELD ALL AROUND BOTH ENDS OF TUBE
2 NATIONAL RUBBER CUSHIONED UNITS TYPE MI-241-B WITH 1" SPACER
SEAMLESS STEEL TUBING 7 5/8" OD x 6 5/8" I.D.
1/2" DIA. DRAIN HOLES (2)
14 RUBBER PADS Nº 39905
4 END PADS Nº 39906
1 1/8" DIA DRILLED HOLES 4 REQ'D
SECTION A-A
15 1/2"
6 1/2"
6 1/2"
1 1/2"
6"
1"
THIS SURFACE MUST BE SMOOTH AND TRUE. POLISH MACHINE IF NECESSARY.
GUSSET 3/8" x 5 1/2" x 12 6/8" 2 REQ'D
WELD ALL AROUND BOTH GUSSET — SECTION B-B
B-B

page 363

VOL. 6 Report 3

73-40 M. Savich

Introduction to noise measurement

1973

Introduction à la mesure du bruit

par

Miron Savich*

RÉSUMÉ

Selon une définition acceptée à l'échelle internationale, le bruit est un son non désirable. La science qui traite du son est l'acoustique. L'unité de mesure de la pression sonore et des niveaux d'intensité du son est le décibel (dB). Le seuil d'audition est la pression sonore la plus faible que l'oreille peut détecter (2×10^{-5} N/m^2 à 1 000 Hz), et représente le point zéro de l'échelle décibel. Les unités décibels sont exprimées dans une échelle logarithmique.

Un son est toujours composé d'un nombre d'ondes sonores de fréquence et de niveau de pression sonore variables. La configuration de distribution des niveaux sonores sur l'échelle de fréquence est appelée le spectre sonore du bruit.

Bruit : son : normes : mesure : expérience

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Droits de la Couronne réservés.

L'intensité du son est la vitesse moyenne à laquelle l'énergie du son traverse une surface unitaire perpendiculaire à la direction de la propagation.

Le niveau de pression sonore en dB est une expression du facteur par lequel la pression d'un son donné dépasse celle d'un son équivalent au seuil de sensibilité de l'oreille. L'unité de niveau sonore est mesurée avec un sonomètre à filtres A, B et C qui modifient la sensibilité du sonomètre selon diverses fréquences. On l'utilise pour mesurer le niveau du son perçu par l'oreille humaine. La somme des niveaux de pression sonore pour toutes les bandes d'octave donne le niveau de son total mais ne renseigne pas sur les ondes sonores dont est composé le bruit. On montre comment combiner les niveaux de bruit exprimés en décibels et les circuits de pondération A, B et C correspondants.

Une analyse complète des normes nationales et internationales permet à chaque mine de déterminer la norme à appliquer dans la zone correspondante.

En annexe figurent des tableaux généraux des niveaux de son enregistrés dans diverses conditions environnementales et dans des exploitations minières types. Les formules utilisées par le Compressed Air and Gas Institute seront utiles dans ces mesures.

Introduction to Noise Measurement

by

Miron Savich*

ABSTRACT

According to an internationally accepted definition, noise is any undesirable sound. The science of sound is acoustics. The unit of measurement of sound pressure and sound intensity levels is the decibel (dB). The threshold of hearing is the lowest sound pressure that the ear can detect (2×10^{-5} N/m^2 at 1000 Hz), and represents the zero point on the decibel scale. Decibel numbers are logarithmic.

A sound is always composed of a number of sound waves of varying frequency and sound pressure level. The pattern of distribution of sound levels over the frequency scale is called the sound spectrum of the noise.

Sound intensity is the average rate at which sound energy is transmitted through a unit area normal to the direction of propagation.

Noise: Sound: Standards: Measurement: Experiment

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The sound pressure level in dB is an expression of the factor by which the pressure of a given sound exceeds that of a sound at the threshold of hearing. The unit of sound level is measured with a noise meter equiped with A, B, and C filters which modify the sensitivity of the noise meter to various frequencies. This is used to measure sound level as perceived by the human ear. The sum of the sound pressure levels for all octave bands gives the total sound level but tells nothing about the sound waves of which the noise is composed. It is shown how to combine decibel levels of noise and the corresponding A, B, and C-weighting networks.

An exhaustive review of National and International Standards enables every mine to set the standard for the corresponding area.

In the Appendix are general tables for sound levels under various environmental conditions and at typical mining operations. The forms used by the Compressed Air and Gas Institute will be useful in measurements.

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1. INTRODUCTION

The purpose of this report is to acquaint the mining engineer practically and theoretically with the measurement of sound and noise.

When a sound source vibrates it causes the molecules in the surrounding air to oscillate. In order that this oscillation may be propagated:

1) there must be a vibrating source;
2) there must be a medium which will transmit, as a wave, the oscillation produced by the source.

2. PHYSICAL PROPERTIES OF NOISE (SOUND)

Noise, music, and speech are three categories of sound. Speech is usually pleasant to the ear. Music may be agreeable, but noise is disagreeable or unwanted sound. Vibrations (small, large, low-frequency, and high-frequency) all have their characteristic effect on the total noise produced.

Elementary definitions and formulae are given for physical properties of noise (sound) and the relationship between the three quantities mentioned: Sound Intensity, Sound Pressure Level and Sound Power Level.

2.1 Sound

Acoustic noise is sound. Two primary attributes of sound are frequency and intensity. The frequency (low or high pitch) is measured in Hz (cps).

$$\lambda = \frac{c}{f} \qquad \text{(Equation 1)}$$

where, c = speed of sound, m/sec;
f = frequency, Hz;
λ = wavelength, m.

The speed with which sound travels in air is dependent on temperature.

$$c = \sqrt{\frac{\gamma \cdot p}{\rho}} \qquad \text{(Equation 2)}$$

p = the local atmospheric pressure, kp/cm^2;
γ = the ratio of the principal specific heat of the gas;
ρ = the local density, kg/m^3

The velocity of sound propagation in various materials is different.

2. 2 Frequency

Frequency is the number of complete cycles of rise and fall in pressure in a given time.

The range of frequencies to which the human ear responds is from 20 to about 20, 000 Hz. Generally speaking, what the ear hears as pitch is the lowest audible frequency component in a complex wave. Pitch is that attribute of auditory sensstion in terms of which sound may be ordered on a scale extending from low to high. Pitch depends primarily upon the frequency of the sound, but it also depends upon the sound pressure and wave form.

Noise is complex in structure. For an understanding of the sound problem in industry, not only the magnitude of the sound must be measured but the frequency. Sound is measured by means of a frequency analysis in octave bands or 1/3-octave bands.

2. 3 Sound Intensity

Sound intensity is the average rate at which sound energy is transmitted through a unit area normal to direction of propagation (joules/m^2/sec or watts/m^2).

In practice, it is found that an extremely large range of sound intensities are audible to man, and, in addition, perceived changes in intensity tend to be proportional to the ratios between the intensities concerned. It is thus more convenient to use a logarithmic unit to measure intensity-- the decibel (dB). By definition, the intensity in decibels,

$$IdB = 10 \log (I/I_0) \text{ dB}, \qquad \text{(Equation 3)}$$

where I is the intensity of a sound, W/m^2, and I_0 is a reference intensity.

The reference intensity 10^{-12} W/m^2 is chosen to be close to the threshold of hearing. The intensity in decibels may then be simply determined from the following equation:

$$IdB = 10 \log I + 120. \qquad \text{(Equation 4)}$$

2.4 Sound Pressure Level

The sound pressure in a freely moving wave is proportional to the square root of the intensity; it is normally expressed in logarithmic units as the root mean square (rms) sound pressure level, SPL, in decibels,

$$SPL = 10 \log (P^2/P_0{}^2) \text{ dB re } P_0 \qquad \text{(Equation 5)}$$

where P is measured in newtons/square metre (N/m^2) or Pa (Pa (pascal) = N/m^2), and

P_0 is the reference pressure, 2×10^{-5} N/m^2,

or

$$\begin{aligned} SPL &= 20 \log (P/P_0) \\ &= 20 \log P + 94, \text{ dB re } 2 \times 10^{-5} \text{ N/m}^2. \qquad \text{(Equation 6)} \end{aligned}$$

The reference pressure is chosen so that the numerical values for intensity and pressure in decibels are similar in many cases.

2.5 Sound Power Level

Sound power of a source is the total sound energy radiated by the source per unit of time.

The sound pressure in a medium is naturally related to the power of the sound source; this power is measured in watts (W). However, because the range of power involved is very great, it is usual to employ a logarithmic scale for sound power. By definition, the sound power level,

$$PWL = 10 \log (W/W_0) \qquad \text{(Equation 7)}$$

where W is the sound power in watts;

W_0 is the reference sound power, 10^{-12} watts;

or $PWL = 10 \log W + 120$ dB (re 10^{-12} watts).

There are no instruments available for the direct measurement of sound power level but in certain circumstances this may be calculated from measurements of sound pressure levels.

2.6 Directivity Factor of a Radiating Noise Source

Most sources of sound of practical interest are directional. This may be of considerable interest in practice as most noise sources do not radiate the sound equally in all directions. If one measures the sound-pressure level in a given frequency band a fixed distance away from the source, different levels will generally be found for different directions.

Numerical measurements of the directionality of a source are the directivity index (DI) and directivity factor (Q):

$$DI_\theta = SPL_\theta - \overline{SPL_s} \text{ dB} \qquad \text{(Equation 8)}$$

and

$$Q_\theta = \text{antilog}_{10} \frac{DI\theta}{10} \text{ dimensionless} \qquad \text{(Equation 9)}$$

where θ is all angles of directional gain, and

$\overline{SPL_s}$ is the sound pressure level in spherical directivity pattern.

2.7 Combining Sound Levels

The relation between the three quantities mentioned (IdB, SPL, PWL) was selected with a definite purpose of providing convenient inter-relation of the three levels. The basis was the reference sound pressure of 2×10^{-5} N/m^2, at a frequency of 1000 Hz. The reference intensity was then selected so that intensity level and sound pressure level would be equal numerically for plane or spherical waves in the air at room temperature and sea level pressure. Under these conditions sound pressure level is defined by,

$$SPL = IdB + 0.2 \text{ dB re } 2\times10^{-5} \text{ N/m}^2 . \qquad \text{(Equation 10)}$$

The reference power level was chosen so that it would be conveniently related to sound pressure level when the surface area over which the power is radiated at the measuring point is expressed in square meters.

$$SPL = PWL - 10 \log_{10} \frac{S}{S_0} + 0.2 \text{ dB re } 2 \times 10^{-5} \text{ N/m}^2$$

(Equation 11)

where S = total surface area of wavefront (metre^2);

S_0 = 1 metre^2.

Sound pressure level of random noise can be added by converting the levels of pressure to intensity units, which may be added arithmetically, and reconverting the resultant intensity to pressure and finally to sound pressure levels in dB. Equations (5) and (6) can be used in free-field conditions for this purpose. There are several circumstances which arise where it is necessary to add or subtract two or more decibel levels. For this purpose, a table (Table 1) or a chart (Figure 1) can be used.

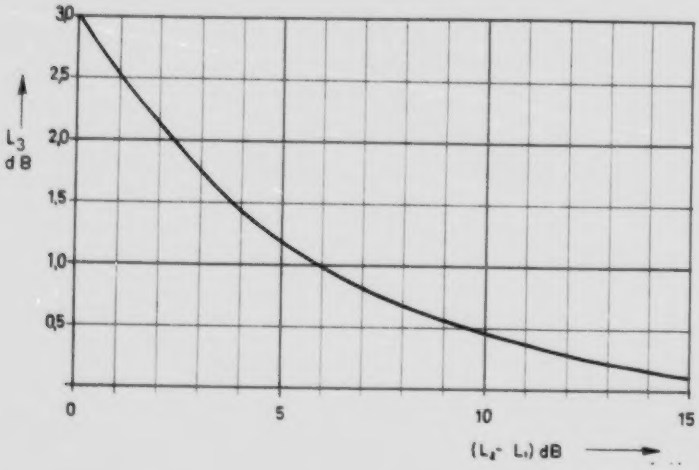


Figure 1: Chart for Addition of Two Decibel Levels, L_1 and L_2, Showing Correction L_3 to be Applied (See Table 1).

TABLE 1

Table for Combining Decibel Levels of Noises with Random Frequency Characteristics

Sum (L_R) of dB Levels L_1 and L_2

Numerical Difference between Levels L_1 and L_2	L_3: Amount to be added to the higher of L_1 or L_2
0.0 to 0.1	3.0
0.2 to 0.3	2.9
0.4 to 0.5	2.8
0.6 to 0.7	2.7
0.8 to 0.9	2.6
1.0 to 1.2	2.5
1.3 to 1.4	2.4
1.5 to 1.6	2.3
1.7 to 1.9	2.2
2.0 to 2.1	2.1
2.2 to 2.4	2.0
2.5 to 2.7	1.9
2.8 to 3.0	1.8
3.1 to 3.3	1.7
3.4 to 3.6	1.6
3.7 to 4.0	1.5
4.1 to 4.3	1.4
4.4 to 4.7	1.3
4.8 to 5.1	1.2
5.2 to 5.6	1.1
5.7 to 6.1	1.0
6.2 to 6.6	0.9
6.7 to 7.2	0.8
7.3 to 7.9	0.7
8.0 to 8.6	0.6
8.7 to 9.6	0.5
9.7 to 10.7	0.4
10.8 to 12.2	0.3
12.3 to 14.5	0.2
14.6 to 19.3	0.1
19.4 to ∞	0.0

Step 1: Determine the difference between the two levels to be added (L_1 and L_2).

Step 2: Find the number (L_3) corresponding to this difference in the table.

Step 3: Add the number (L_3) to the higher of L_1 or L_2 to obtain the resultant level ($L_R = L_1 + L_2$).

The order in which the various band levels are combined is unimportant. A good procedure for adding a series of dB values is to begin with the highest levels so that calculations may be stopped when lower values are reached which do not add significantly to the total.

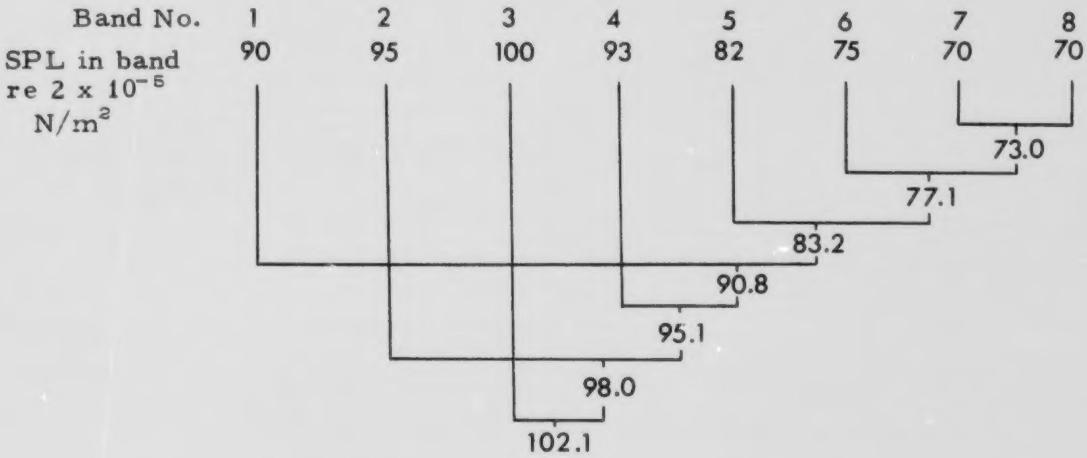

Band No.
1
2
3
4
5
6
7
8
SPL in band re 2 x 10^{-5} N/m^2
90
95
100
93
82
75
70
70
73.0
77.1
83.2
90.8
95.1
98.0
102.1

Figure 2: Determination of an Over-All SPL (8 Frequency Bands) = 102 dB (re 2 x 10^{-5} N/m^2).

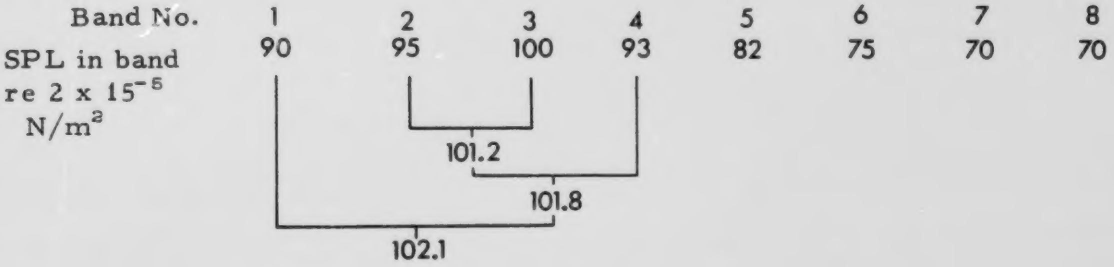

Band No.
1
2
3
4
5
6
7
8
SPL in band re 2 x 15^{-5} N/m^2
90
95
100
93
82
75
70
70
101.2
101.8
102.1

Figure 3: Determination of an Over-All SPL (8 Frequency Bands) = 102 dB(re 2 x 10^{-5} N/m^2), Beginning with the Highest Levels.

Subtraction is important when machine noise is measured in the presence of background noise. For signal/background ratios greater than 10 dB the effect of the background noise upon measurement of signal can, in most cases, be neglected (Figure 4).

The procedure to be applied to correct for background noise is as follows:

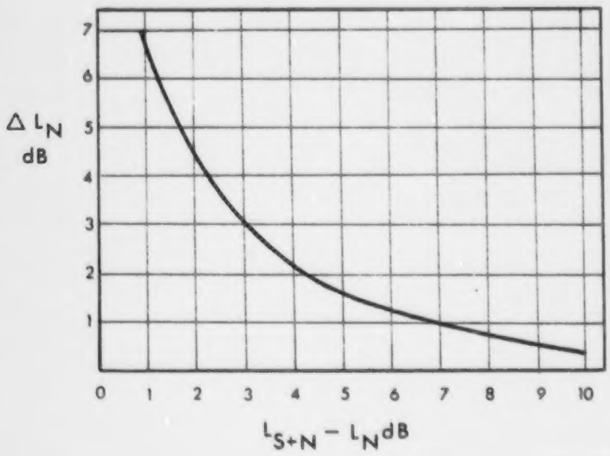


Figure 4: Decibel Subtraction Chart

1. The signal + background noise, L_{S+N}, is first measured (normal measurement), after which the distinct signal source is shut off and the background noise, L_n, measured alone. The difference, $L_{S+N} - L_n$, to be calculated
2. The dB value ΔL_n, to be subtracted from the L_{S+N} value, is found from the chart (Figure 4).

3. The result, $L_{S+N} - \Delta L_n$, is the correct level of the signal being measured. In practice, if the noise level measured when the machine being investigated is shut off, i. e., the background noise level, is more than 10 dB lower than the noise level measured with the machine operating, no correction of the measured result is necessary. If the difference between the total noise level and the background noise level is less than about 3 dB, it is necessary to move the machine to a quieter place. For differences between 10 dB and 3 dB, all approximate corrections can be derived from the chart (Figure 4).

4. A-, B-, and C-Weighting Networks. The corresponding values found in many noise regulations (Figure 5) may be calculated from noise spectrum values such as those in the above example if the correction numbers given in Table 2 are first applied.

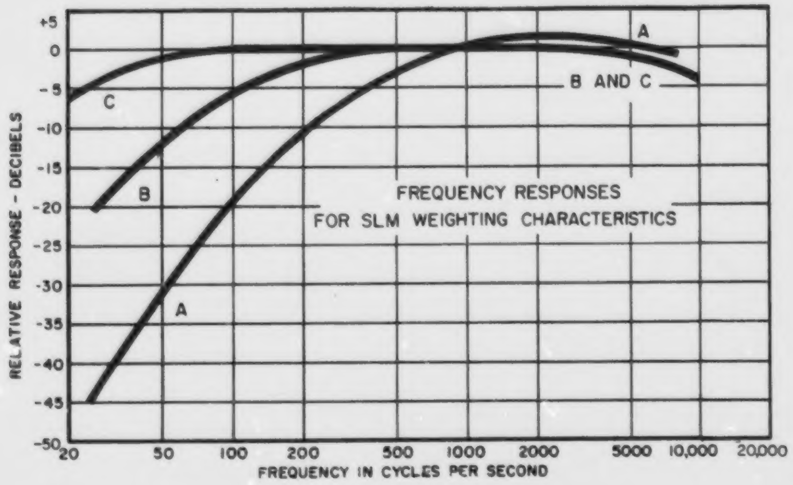


Figure 5: The U. S. A. Standardized Weighting Curves for Sound Level Meters (S 1.4, 1961).

These networks were designed to approximate the loudness level sensitivity of the human ear when listening to pure tones. The A-weighted reading is used to estimate the probability of hearing damage in industry. The B-weighting network is rarely used. The C-network is used to limit the low- and high-frequency response of the instrument.

TABLE 2

Adjustment of a Linear Spectrum to Electrical A-, B-, and C-Weighting Networks for the Sound Level Meter *

Frequency, Hz	A-Weighting Relative Response, dB	B-Weighting Relative Response, dB	C-Weighting Relative Response, dB
31.5	- 39.4	-17.1	-3.0
63	- 26.2	- 9.3	-0.8
125	- 16.1	- 4.2	-0.2
250	- 8.6	- 1.3	0
500	- 3.2	- 0.3	0
1,000	0	0	0
2,000	+ 1.2	- 0.1	-0.2
4,000	+ 1.0	- 0.7	-0.8
8,000	- 1.1	- 2.9	-3.0

Ref. "Proposed USA Standard for Sound Level Meters", a revision of S 1.4, 1961, American National Standards Institute, Inc.

* These numbers assume a flat, diffuse-field response for the sound level meter and microphone.

A general-purpose Sound Level Meter shall cover the frequency range 315 - 8000 Hz and shall include the three different response curves, A, B, and C. The microphone shall be omnidirectional. The indicating meter must be capable of adding together two pure tones according to the root mean square law.

The U.S.A. standard for Sound-Level Meter (S 1. 4, 1961) requires that three alternate frequency-response characteristics be provided in the instrument (Figure 5).

The most consistent results are found if the noises that are being compared are similar in character (hammer drills). It is also useful in preliminary ratings of similar ambient noises for the human reactions that may occur.

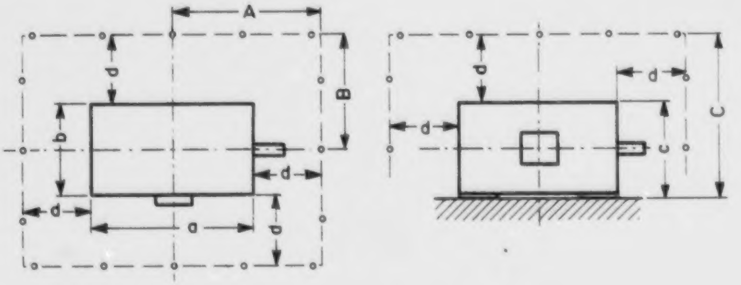
In order to avoid confusion in reporting the characteristics of noise, it is always necessary to indicate the reference quantity on which the decibel scale is based, for example: re 2×10^{-5} N/m^2 in Equations 5 and 6.

3. STANDARDS

The greatest opportunity for an engineer in the field of noise control should be the selection of equipment which has been designed to produce low noise levels. Unfortunately, the manufacture of such equipment is limited and, for most equipment groups, non-existent.

Much more is known about the general acoustic principles of noise control than about the application of these principles to specific noise sources. Some equipment manufacturers direct little effort toward noise reduction, whereas others direct considerable research effort to the design and development of quiet equipment. The progress has been made by them but is small in comparison to the increase in industrial noise. Acceptance by industry has been less than favorable because of increased costs.

Manufacturers must be assured of a market for quiet equipment before the cost of research, design, or modification can be assumed. The demand for quiet equipment can be made known only by buyers incorporating noise control requirements in their engineering specifications.



$A = \frac{a}{2} + d\,[m]$ $B = \frac{b}{2} + d\,[m]$ $C = c + d\,[m]$ $d = 1\,m$

Figure 6: Position of Measurement Points
(ISO Recommendation R 495).

At present, many equipment manufacturers will provide noise data upon request but before such data can be meaningful, the measurement procedure and room in which the tests are made must be clearly specified. A comparison of the data received from various manufacturers is impossible without such information.

The need for an agreement in measure, number, and shape has led to the formation of standards which have national and international importance.

3.1 International Standards

The object of international standardization is to set up rules which facilitate the international exchange of goods and services and technological and economic activity. At present, two international bodies exist for international standardization: the International Electrotechnical Commission (IEC) and the International Organization for Standardization (ISO).

A number of international recommendations related to the use of our measurements are summarized below.

International Electrotechnical Commission

IEC Recommendation, Publication 50 (08). International Electrotechnical Vocabulary, Electro-Acoustics (1960).

IEC Recommendation, Publication 118. Recommended Methods for Measurements of the Electro-Acoustical Characteristics of Hearing Aids (1959).

IEC Recommendation, Publication 123. Recommendations for Sound Level Meters (1961).

IEC Recommendation, Publication 179. Precision Sound Level Meters (1965).

IEC Recommendation, Publication 225. Octave, Half-Octave and Third-Octave Band Filters Intended for the Analysis of Sounds and Vibrations (1966).

IEC Recommendation, Publication 268-1. Sound System Equipment Part 1: General (1968).

IEC Recommendation, Publication 268-1A. First Supplement to Publication 268-1. Sound System Equipment. Part 1: General (1970).

IEC Recommendation, Publication 268.2. Sound System Equipment. Part 2: Explanation of General Terms (1971).

IEC Recommendation, Publication 268-3. Sound System Equipment. Part 3: Sound System Amplifiers (1969).

IEC Recommendation, Publication 268-3A. First Supplement to Publication 268-3. Sound System Equipment. Part 3: Sound System Amplifiers (1970).

IEC Recommendation, Publication 268-14. Sound System Equipment. Part 14: Mechanical Design Features (1971).

International Organization for Standardization

ISO Recommendation R 31 Part VII. Quantities and Units of Acoustics (1965).

ISO Recommendation R131. Expression of the Physical and Subjective Magnitudes of Sound or Noise (1959).

ISO Recommendation R140. Field and Laboratory Measurements of Airborne and Impact Sound Transmission (1960).

ISO Recommendation R226. Normal Equal-Loudness Contours for Pure Tones and Normal Threshold of Hearing Under Free Field Listening Conditions (1962).

ISO Recommendation R266. Preferred Frequencies for Acoustical Measurements (1962).

ISO Recommendation R357 (Supplementary to R131). Expression of the Power and Intensity Levels of Sound or Noise (1963).

ISO Recommendation R362. Measurement of Noise Emitted by Vehicles (1964).

ISO Recommendation R495. General Requirements for the Preparation of Test Codes for Measuring the Noise Emitted by Machines (1966).

ISO Recommendation R512. Sound Signaling Devices on Motor Vehicles, Acoustic Standards and Technical Specifications (1966).

ISO Recommendation R532. Method for Calculating Loudness Level (1966).

ISO Recommendation R1680. Test Code for the Airborne Noise Emitted by Rotating Electrical Machinery (1970).

ISO Recommendation R 1996. Acoustics, Assessment of Noise with Respect to Community Response (1971).

ISO Recommendation R1999. Acoustics, Assessment of Occupational Noise Exposure for Hearing Conservation Puposes (1971).

ISO Recommendation R2017. Vibration and shock-isolators-specifying characteristics (Guide for selecting and applying resilient devices).

ISO Recommendation R2041. Vibration and Shock-Terminology.

ISO Recommendation R----. Test code for the measurement of sound from pneumatic equipment.

3.2 National Standards

Significant achievements have been made by several manufacturing groups in overcoming the confusion of noise measurement and data reporting. Standard methods for sound testing and data reporting have been developed by the Air Moving and Conditioning Association; the American Society of Heating, Refrigeration, and Air Conditioning Engineers, Inc.; the American Gear Manufacturers Association; the National Electrical Manufacturers Association; and the Institute of Electrical and Electronic Engineers for their respective manufacturing groups. Many equipment manufacturers have no standard methods for sound testing and data reporting.

Existing standards related to noise ratings, noise measurements, and noise tests are listed by title under the name of the organization or society using the standard.

American Gear Manufacturers Association

AGMA Standard 293.03. Specification for Measurement of Sound on High Speed Helical and Herringbone Gear Units (1968).

American National Standards Institute

ASA S1.1-1960. American Standard Acoustical Terminology.

ASA S1.2 - 1962. American Standard Method for the Physical Measurement of Sound.

ANSI S1.4 - 1971. American National Standard Specifications for Sound Level Meters.

USAS S1.6 - 1967. USA Standard Preferred Frequencies and Band Numbers for Acoustical Measurements.

ANSI S1.8 - 1969. American National Standard Preferred Reference Quantities for Acoustical Levels.

ASA S1.10 - 1966. American Standard Method for the Calibration of Microphones.

ASA S1.11 - 1966. American Standard Specification for Octave, Half-Octave, and Third-Octave Band Filter Sets.

USAS S1.12 - 1967, USA Standard Specifications for Laboratory Standard Microphones.

ANSI S1.13 - 1971. American National Standard Methods for the Measurement of Sound Pressure Levels.

ASA S3.1 - 1960. American Standard Criteria for Background Noise in Audiometer Rooms.

ASA S3.3 - 1960. American Standard Methods for Measurement of Electroacoustical Characteristics of Hearing Aids.

USAS S3.4 - 1968. USA Standard Procedure for the Computation of Loudness of Noise.

ANSI S3.6 - 1969. American National Standard Specifications for Audiometers.

USAS S3.8 - 1967. USA Standard Method of Expressing Hearing Aid Performance.

ANSI S5.1 - 1971. . American National Standards Test Code for the Measurement of Sound from Pneumatic Equipment.

ASA Y10-11 - 1963. American Standard Letter Symbols for Acoustics.

ASA Z24.9 - 1969. American Standard Method for the Coupler Calibration of Earphones.

ASA Z24.22 - 1957. American Standard Method for the Measurement of the Real-Ear Attenuation of Ear Protectors at Threshold.

American Society of Heating, Refrigerating and Air-Conditioning Engineers

ASHRAE Standard 36-62. Measurement of Sound Power Radiated from Heating, Refrigerating and Air-Conditioning Equipment.

ASHRAE Standard 36A-63. Method of Determining Sound Power Levels of Room Air Conditioners and Other Ductless, Through-The-Wall Equipment.

ASHRAE Standard 36B-63. Method of Testing for Rating the Acoustic Performance of Air Control and Terminal Devices and Similar Equipment.

American Society for Testing and Materials

ASTM Designation: C634-69. Standard Definitions of Terms Relating to Acoustical Tests of Building Constructions and Materials.

Anti-Friction Bearing Manufacturers Association

AFBMA Standard No. 13. Rolling Bearing Vibration and Noise (1968).

Association of Home Appliance Manufacturers

AHAM Standard SR-1. Room Air Conditioner Sound Rating (1971).

Compressed Air and Gas Institute

CAGI Test Code. CAGI-PNEUROP Test Code for the Measurement of Sound from Pneumatic Equipment (1969).

Institute of Electrical and Electronic Engineers

IEEE No. 85, Test Procedure for Airborne Noise Measurements on Rotating Electric Machinery (1965).

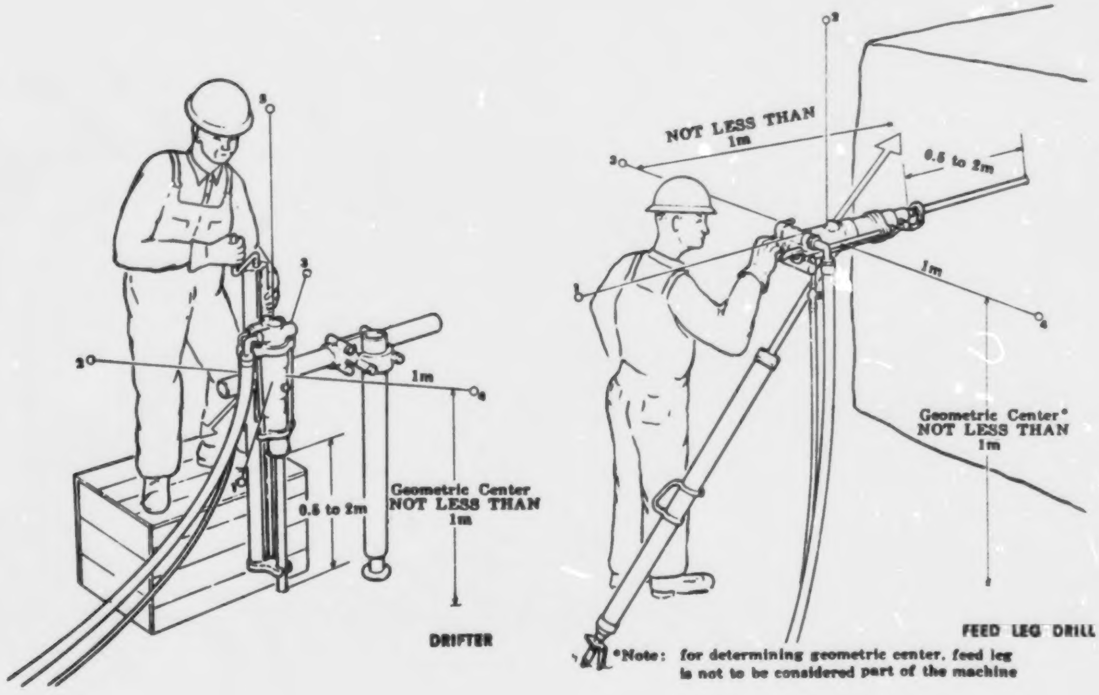
IEEE No. 151. Standard Definitions of Terms for Audio and Electro-Acoustics (1965).

National Machine Tool Builders Association

NMTBA Standard. Noise Measurement Techniques (1970).

Society of Automotive Engineers

SAE Standard J672a. Exterior Loudness Evaluation of Heavy Trucks and Buses (1970).


5
3
2
1m
4
0.5 to 2m
Geometric Center
NOT LESS THAN
1m
DRIFTER
2
NOT LESS THAN
1m
3
0.5 to 2m
1
1m
4
Geometric Center*
NOT LESS THAN
1m
FEED LEG DRILL

*Note: for determining geometric center, feed leg is not to be considered part of the machine

Figure 7: Test Code for the Measurement of Sound from Pneumatic Equipment (ISO and CAGI).

SAE Recommended Practice J919. Measurement of Sound Level at Operator Station (1966).

SAE Recommended Practice 919a. Sound Level Measurements at the Operator Station for Agricultural and Construction Equipment (1971).

SAE Standard J952b. Sound Levels for Engine Powered Equipment)1969).

SAE Recommendation Practice J 184. Qualifying a Sound Data Acquisition System (1970).

SAE Recommended Practice J336. Sound Level for Truck Cab Interior (1968).

SAE Recommended Practice J366. Exterior Sound Level for Heavy Trucks and Buses (1969).

4. EXPERIMENT: NOISE CONTROL DEMONSTRATION KIT

Figure 8: Noise Control Demonstration Kit.

A leading noise control engineer designed this kit to show people how to reduce noise. The audible effects of controlling vibration and air-borne and structure-borne noise can be demonstrated dramatically with this apparatus.

The kit is valuable for training engineers to control noise, teaching principles of acoustics to science classes, explaining the proper use of noise control materials to customers, etc.

Most kit parts are common objects or materials familiar to everyone. Two electric bells stand on a wooden base and are connected to a transformer through pushbutton switches. Any of the noise control materials supplied can be used on one bell and the audible effect shown by comparison with the other bell.

Sound control materials supplied are two cylinders of tin-plated steel with covers and two smaller cylinders of fiber glass with covers. Vibration control materials supplied are two rings of soft rubber tubing, two C-shaped pieces of damping felt and rubber bands.

The kit operates on ordinary power supply (120 volts, 60 cycles) and the power transformer contains a self-resetting circuit breaker for safe operation even by children.

APPENDIX

TABLE A-1

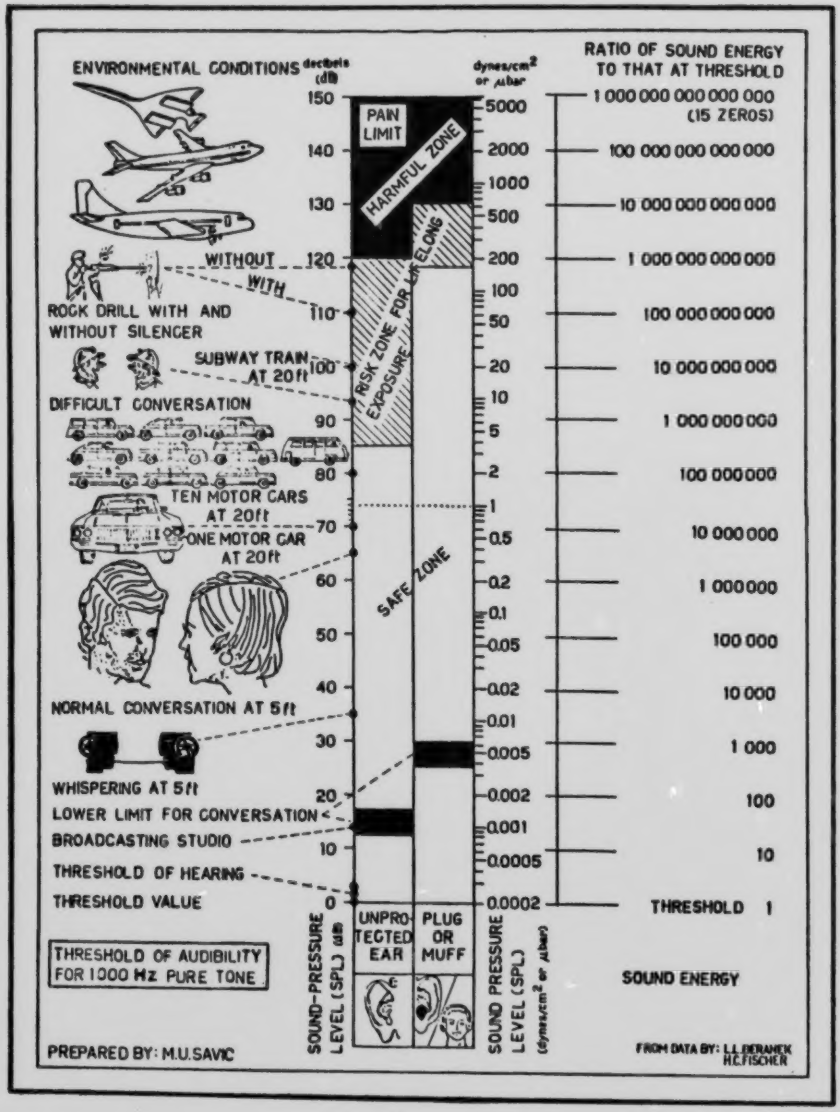


TABLE A-2

Table —A-weighted sound levels at typical mining operations

GENERAL	
Trucks (15 ton up)	89–101 dBA
Shovels (diesel)	91–107
Shovels (electric)	83–91
Bulldozers	102–106
Cranes	88–99
End loaders	95–97
Road graders	91–96
Locomotives (diesel)	88–100
ORE AND STONE	
Primary crushers	88–91
Secondary crushers	91–101
Vibrating screens	98–109
Rod and ball mills	89–104
Pneumatic drills	
surface	97–98
underground	112–121
Diamond drill	101
COAL	
Continuous miners	94–96
Loaders	95–100
Shuttle cars	88–92
Cutter	97
Roof drill	93–98
Locomotives (electric)	84–95
Washing and screening	92–104
Pneumatic drills, underground	117–122

By JAMES H. BOTSFORD

COMPRESSED AIR AND GAS INSTITUTE

SOUND LEVEL TEST REPORT FOR SMALL MACHINES PER CAGI-PNEUROP CODE

REPORT FORM NO. 8.3.1

SUBJECT:

Model: ______________ Manufacturer: ______________ Serial: ________
Rated Speed & Capacity: ______________________________
Description: ______________________________

TEST CONDITIONS:

Environment: ______________ Indoors ______________ Outdoors
Tested: ______________ Running Free ______________ With Load Imposed
Operating Speed as Tested: ______________ Air Pressure Supplied: ________ Bars
Height of Subject (G.C.) Above Reflecting Plane: ______________ Meters
Reflecting Plane Composition: ______________________________
Remarks: ______________________________

INSTRUMENTATION:

Microphone: ______________ No. ________
Sound Level Meter: ______________ No. ________
Octave Band Analyser: ______________ No. ________
Calibrator: ______________ No. ________
Other: ______________ No. ________

DATA:

dB Ref. 2×10^{-5} N/m^2		BACKGROUND	LOCATION *					AV.
			1	2	3	4	5	
MID-BAND FREQ. H_z	dB A							
	63							
	125							
	250							
	500							
	1 k							
	2 k							
	4 k							
	8 k							

*Corrected for background sound. Readings having 3 dB corrections must be reported in brackets. Only octave bands of interest per paragraph 5.4 need to be reported.

TESTED BY: ______________________ DATE: ______________
REPORTED BY: ______________________ DATE: ______________

Sketch showing microphone locations, orientation of the subject, (direction of exhaust and size of load cell where applicable).

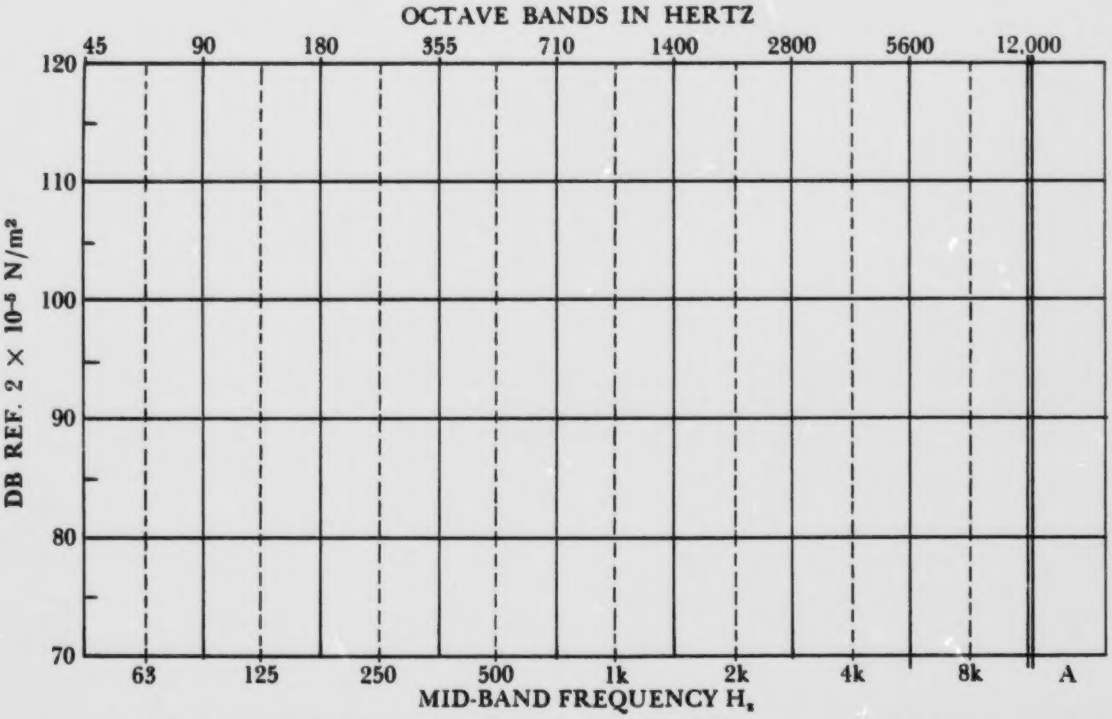


DIAGRAM SHOWING AVERAGE SOUND LEVELS AND BACKGROUND SOUND LEVELS AT TIME OF TEST

COMPRESSED AIR AND GAS INSTITUTE

SOUND LEVEL TEST REPORT FOR STATIONARY PLANT PER CAGI-PNEUROP TEST CODE

REPORT FORM NO. 8.3.3

SUBJECT:

Model: ____________ Manufacturer: ____________ Serial: ________
Rated Compressor Speed: ____________ Capacity: ____________ Pressure: ________
Type of Driver: ____________ Speed: ________
Auxiliaries such as Gears: ____________
Description: ____________

TEST CONDITIONS:

Distance from Subject to Microphone: ____________ Meters
Operating Speed as Tested: ____________
Height of Microphone Above Reflecting Plane: ____________ Meters
Reflecting Plane Composition: ____________
Remarks: ____________

INSTRUMENTATION:

Microphone: ____________ No. ________
Sound Level Meter: ____________ No. ________
Octave Band Analyser: ____________ No. ________
Calibrator: ____________ No. ________
Other: ____________ No. ________

DATA:

dB Ref. 2×10^{-5} N/m^2		BACK-GROUND	LOCATION *										AV.
			1	2	3	4	5	6	7	8	9	10	
MID-BAND FREQ. H_z	dB A												
	63												
	125												
	250												
	500												
	1 k												
	2 k												
	4 k												
	8 k												

*Corrected for background sound. Readings having 3 dB corrections must be reported in brackets. Only octave bands of interest per paragraph 7.3 need be reported.

TESTED BY: ____________ DATE: ____________
REPORTED BY: ____________ DATE: ____________

Sketch showing microphone locations, orientation of the subject, (direction of exhaust and size of load cell where applicable).

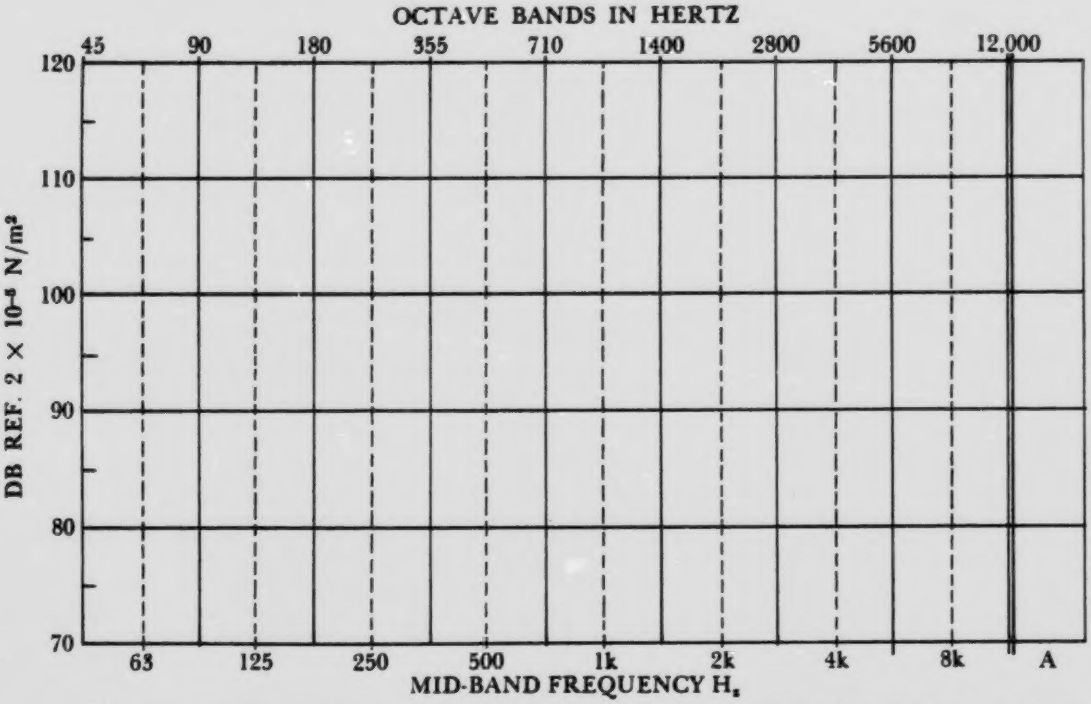


DIAGRAM SHOWING AVERAGE SOUND LEVELS AND BACKGROUND SOUND LEVELS AT TIME OF TEST

Page 397

VoL. 6 Report 4

74-76 M. Savich and R.A. Washington

Measurement and control of

noise in Canadian mines:

a review and progress report

1974

Mesure et réduction du bruit dans les mines canadiennes :
Rapport d'analyse et d'étape

par

M. Savich * et R.A. Washington*

RÉSUMÉ

Un très bref exposé des connaissances actuelles sur les dangers d'exposition à un bruit excessif, des techniques de mesure du bruit et des méthodes de lutte contre le bruit, en particulier dans les mines souterraines au Canada, est présenté. Un résumé des travaux de recherche et développement effectués dans ces domaines au laboratoire d'Elliott Lake du Centre de recherche minière est aussi inclus.

Les sujets sont autant que possible traités d'un point de vue pratique afin de permettre aux ingénieurs miniers d'en tirer les données essentielles sans une connaissance approfondie de la théorie du bruit.

Bruit : exploitation minière : revue

* Chercheur scientifique, Laboratoire d'Elliott Lake, Centre de recherche minière, Direction des mines, Ministère de l'Énergie, des Mines et des Ressources, Elliott Lake (Ontario).

Droits de la Couronne réservés.

Measurement and Control of Noise in Canadian Mines: A Review and Progress Report

by

M. Savich* and R. A. Washington*

- - - - - - - - - - - - - - - - -

ABSTRACT

A very brief account is given of current knowledge of the hazards of exposure to excessive noise, noise measurement techniques, and noise control methods, particularly in Canadian underground mines. A summary is included of research and development work in these fields which is being conducted at the Elliot Lake Laboratory of the Mining Research Centre.

The subjects are approached from a practical point of view whenever possible, to assist mining engineers to grasp the essentials without a detailed knowledge of noise theory.

Noise: Mining: Review

* Research Scientists, Elliot Lake Laboratory, Mining Research Centre,
Mines Branch, Department of Energy, Mines and Resources,
Elliot Lake, Ontario.

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SUMMARY

Noise levels are often very high (up to 115 dBA) in the vicinity of heavy mechanical equipment (drills, scooptrams, trucks) used in underground Canadian mines. Lengthy exposure without protection at such levels may cause permanent hearing damage. Excessive employee exposure in these cases is commonly avoided by providing hearing protection such as ear muffs, plugs, or both, but these devices should only be regarded as temporary measures. Reduction of noise emission by redesign of the equipment, by provision of mufflers or silencers, or by isolation of the equipment or the operator is considered to be preferable because it offers a permanent solution to the problem and removes the danger of excessive exposure due to misapplication of hearing protection equipment.

Considerable variation has been found in the noise level associated with mining equipment, depending on the age and condition of the equipment, the location in which it is used, and the operating technique. Each mine and each working place probably should be considered as an individual problem, and data obtained elsewhere should only be used as a rough guideline. In order to enable a complete analysis of noise problems, a comprehensive survey should be undertaken of each working place where a problem is suspected. The Elliot Lake Laboratory of the Mining Research Centre is capable of undertaking such

a survey on request, and after analysis of the data can advise on the best solution to any difficulty in protecting the hearing of employees in Canadian mines.

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1. INTRODUCTION

It has only been recognized recently that exposure of employees to excessive noise can be a serious problem (1, 2). Increasing use of heavy mechanical equipment in underground mining operations has resulted not only in increased productivity, but also in a marked rise in cumulative noise exposure of underground miners (3, 4, 5). Because the total labour force employed in underground mining has not grown in proportion to the rise in productivity and noise levels resulting from mechanization, the number of miners exposed has not been as great as it might otherwise have been. This has, in one sense, been fortunate, as the number of employees who have suffered problems of hearing impairment due to excessive noise exposure has been minimal. Nevertheless, considerable effort is required to ensure that the labour force, while enjoying the economic returns of increased productivity, does not suffer hearing impairment due to excessive noise exposure.

The physiological effects of long exposure to high intensity noise* may vary greatly depending on the individual, on the sound wave frequencies and intensities, and on the lengths of exposure (2, 6, 7, 8). Intense, sudden noise such as that produced by a nearby explosion or a pile driver, is called impact noise. It may severely damage the middle and inner ear, rupturing the eardrum and dislocating the bones of the ossicular chain. At a slightly less intense level, noise may produce temporary or, if a long exposure is involved, permanent loss of hearing. This loss is usually most severe for sound frequencies above 2000 Hz. Some experimental data also indicate that high levels of noise intensity for long periods may cause increased nervous tension (both during exposure and for some time afterward), fatigue, operator error, and reduced job performance efficiency. Moreover, by directly interfering with speech and indirectly by causing temporary or permanent loss of hearing acuity it is believed that high intensity noise levels may represent a serious safety hazard. It must be emphasized that the evaluation of the physiological effects of noise is complicated by the fact that these effects vary to a considerable degree from one individual to another. Only general conclusions can be drawn, based on observations on a large number of people. Thus the effects of long exposure of any individual to high noise levels cannot be accurately predicted; the best that can be done is to estimate the probability that a significant hearing loss (or other result) may occur (2).

---

* Noise usually consists physically of a broad band of frequencies in the audible range of 20 to 20000 Hz; the most important frequencies occur in the range from 300 to 8000 Hz.

Noise sources in industry, although similar in many respects to those in underground mining, differ in one very important aspect. It is only infrequently that noisy industrial equipment is totally enclosed in a small space, with the operator inside the enclosure. This is often the case, however, in a mining situation, and a major consideration in mining operations is the problem of controlling noise levels in confined spaces*. Because the available space is extremely limited in underground mining, and equipment must be moved frequently, it may be impractical to use the standard noise protection technique of placing either the equipment or the operator in a sound-proof enclosure. In such a case other methods must be found.

Noise is often defined (3, 4) as undesirable or disagreeable sound. By this definition even sound which is ordinarily considered pleasant, e. g. normal speech or music, may be considered to be noise if it is unpleasant, e. g. shouting or very loud music. It is thus apparent that a quantitative evaluation of noise must be based primarily on the sound intensity rather than its frequency or other qualities. For example, consider a railway train, whistling as it approaches a level crossing late at night. This would be an annoying noise in a residence 100 yards from the crossing. In a home half a mile away, it might be merely a pleasant reminder of childhood dreams of travel, although the sound qualities such as frequency, range and tone would be little different at the two locations.

Sound intensity has been defined as the average rate of transmission of sound energy through unit area normal to the direction of propagation (9). However, absolute measurements of sound energy are difficult to obtain, and are usually unnecessary. A relative measurement, which will simulate the response of the normal human ear, is much more useful and practical. Such a measurement requires the establishment of a basic value to which all observations may be related, and the threshold of hearing for the normal ear has been generally accepted as the basis for comparison. Moreover, because sound consists of pressure waves in air, because noise exposure hazard is related to sound pressure, and because sound detectors such as microphones are in fact highly sensitive pressure measuring devices, practical sound intensity measurements are made in sound pressure units. The basic sound pressure level (SPL) unit is the bel (cf. electrical power measurements), but because this has proven to be a rather large unit in practice, a smaller unit, the decibel (= 0. 1 bel), is used. The SPL of any sound or noise in decibels (dB) is therefore defined as,

---

* This problem is exemplified by the fact that a pneumatic drill on surface has a typical noise level of 100 to 105 dBA; underground, it may have a noise level of 110 to 120 dBA (4).

$$\mathrm{SPL} = 10 \log (P^2/P_0{}^2) \text{ dB} \qquad \text{(Equation 1)}$$

where P = root mean square sound pressure, N/m^2, and

P_0 = reference pressure (hearing threshold), $2 \times 10^{-5}\ N/m^2$.

Inserting the value of P_0 in Equation 1, one obtains the practical equation for sound pressure level,

$$\mathrm{SPL} = 20 \log P + 94 \quad \text{(dB)} \qquad \text{(Equation 2)}$$

Sound pressure level is thus a logarithmic function of the sound pressure. This type of function was selected for sound intensity measurement because it was found to correlate well with the response of the normal human ear, which tends to be logarithmic.

If it is desired to employ English units for sound pressure rather than S. I. units, the reference pressure (P_0) is taken to be 2.94×10^{-9} psi. Inserting this value in Equation 1 and simplifying gives,

$$SPL = 20 \log P + 171 \qquad \text{(Equation 3)}$$

for sound pressure level. However, because sound pressure level is proportional to the logarithm of the ratio of two sound pressures, the value found for the SPL is independent of the units used for the sound pressures, and no advantage is gained by employing units that are not widely used in noise measurement. It is therefore strongly recommended that underground noise measurements be made to conform with accepted practice, and that Equation 2 be employed (i. e. that the reference pressure, P_0, be taken as $2 \times 10^{-5}\ N/m^2$) when necessary rather than Equation 3.

Noise level meters are designed to indicate sound pressure level directly in decibels, relative to the root mean square sound pressure at the threshold of hearing, as defined above. However, their response is modified electronically (as described below) to simulate the response of the human ear, because their main purpose is to evaluate the hazard of excessive noise exposure.

The normal human ear is not equally sensitive to sound pressure levels at all frequencies in the audible range of 20 Hz to 20000 Hz. Its maximum sensitivity lies in the frequency range from about 500 to 4000 Hz, and its sensitivity (particularly for frequencies below 500 Hz) also varies inversely with the SPL* Sound detecting devices (e.g. microphones), on the other hand, frequently have a relatively flat response to sound intensities at frequencies throughout the audible range, as well as above and below this range. Therefore, it was necessary to devise an electronic filter circuit which would attenuate the output of the detector at each frequency so as to give a reading corresponding to the response of the ear to that frequency. To account for the variation in response with sound intensity, three filter networks were developed which represent fairly accurately the response of the ear to different frequencies for SPL < 55 dB (A-network), 55 dB < SPL < 85 dB (B-network) and SPL > 85 dB (C-network). Table 1 indicates the weighting (attenuation) factors which apply in each octave band. The A-weighted response gives much attenuation below 500 Hz, the C-weighted response is almost flat over the audible range, and the B-weighted response is intermediate. At frequencies above and below the range of the table the C-weighted attenuation increases sharply, permitting the use of C-network weighting when the instrument response to subsonic or ultrasonic frequencies must be limited and a flat response is needed in the

---

* i.e. for frequencies below 500 Hz, the ear is more responsive to low intensity (low SPL) noise than to high intensity (high SPL).

TABLE 1

A-, B-, and C-Weighted Response of a Sound Level Meter to 100 dB Pure Tones vs Octave Band Centre Frequency (8, 10)

Octave Band Centre Frequency	A-Weighted Response, dBA	B-Weighted Response, dBB	C-Weighted Response, dBC
31.5	60.6	82.9	97.0
63	73.8	90.7	99.2
125	83.9	95.8	99.8
250	91.4	98.7	100.0
500	96.8	99.7	100.0
1000	100.0	100.0	100.0
2000	101.2	99.9	99.8
4000	101.0	99.3	99.2
8000	98.9	97.1	97.0

audible range. B-weighting is infrequently used, and the A-weighting network is the most widely used of all for noise exposure hazard measurement, because the electronic circuit produces results that can best be correlated with the observed probability of hearing impairment caused by industrial noise, with speech interference, and with other factors such as loudness level* (8). Good quality noise level meters have all three weighting networks built in, so that there is ordinarily no need to carry out an octave band analysis** of a noise source and calculate the corrections; this is performed electronically by the instrument, and the operator need only record the reading.

An immediate consequence of the growing concern over excessive employee exposure to high noise levels has been the establishment of safe exposure limits. In some cases, limits were set originally by voluntary agreement within an industry, and inspection and

---

* A subjective rating of average noise loudness by a panel of listeners.

** An octave band analysis usually involves measuring the SPL for 9 octave bands with centre frequencies shown in Table 1. An octave band is a range of frequencies that varies by a factor of two, e. g. 45 Hz to 90 Hz. The centre frequency of this octave band, C. F., is defined as:

$$\begin{aligned}\log(\text{C.F.}) &= \log 45 + 1/2 \log \frac{90}{45} \\ &= \log 45 + 1/2 \log 2 \\ &= \log 45 + 0.15 \\ &= 1.65 + 0.15 \\ &= 1.80 \\ \therefore\ \text{C.F.} &= 63\ \text{Hz.}\end{aligned}$$

The other centre frequencies in Table 1 were established similarly.

regulation were self-performed. At present, the usual practice involves the establishment of safe limits, inspection, and enforcement by a branch or agency of the government (provincial or federal) which has jurisdiction over the industry in question.

Current Canadian noise exposure limits are usually based on U.S. standards, such as those adopted by the American Conference of Governmental Industrial Hygienists (11), possibly with minor variations. These limits have been established for underground mining as regulations of an appropriate provincial government agency, because (in general) the provinces have the authority to regulate mining in Canada. Although the values continue to be debated and modified from time to time, they represent a consensus of expert opinion based on the best available experimental data. The Ontario regulations, which are typical, have been set by the Ministry of Natural Resources, Division of Mines, Mines Engineering Branch. These regulations became effective 1/7/74, and are summarized in Table 2. To estimate exposure where the noise level is variable, the OSHA* exposure coefficient, $\sum_i \frac{t_i}{T_i}$, must be calculated, where t_i is the observed time of exposure at sound pressure level i, and T_i is the maximum allowable exposure time at that level; if the summation gives a value greater than 1, the exposure is considered excessive. An artificial example is shown in Table 3.

---

* U. S. Occupational Safety and Health Administration.

TABLE 2

Province of Ontario
Noise Control and Hearing Protection Code

Sound Pressure Level, dBA (Slow Response)	Max. Daily Exposure Limit, Hours
90	8
92	6
95	4
97	3
100	2
102	1.5
105	1
107	0.75
110	0.50
115	0.25
No exposure is permitted at a level above 115 dBA, except for impact noise (short duration, e. g. an explosion). Impact noise should not exceed 140 dBA (normal pain threshold).	

Because $\sum_i \frac{t_i}{T_i} > 1$ in this case, the combined exposure would be in excess of the permissible limit. (Exposure time limits were taken from Table 2 for the sound pressure level next higher than the observed level.)

Predictions of future developments are probably of little value, but it is not considered likely that noise exposure limits will become less stringent. It would therefore seem to be prudent to apply

TABLE 3

Sample Calculation of Exposure for Variable Noise Levels

SPL Observed, dBA (i)	Observed Exposure Time, hrs (t)	Exposure Time Limit, hrs (T)	t/T
89	4	∝ *	0
93	3	4	0.75
98	0.75	2	0.38
109	0.25	0.5	0.50
		$\frac{t_i}{T_i}$ =	1.63

* The table value for exposure at 90 dBA or less is 8 hours. Therefore, only exposures at more than 90 dBA are included in cumulative exposure calculations, i.e. the exposure limit is assumed to be infinite for noise levels of 90 dBA or less.

the maximum possible effort to achieving exposures well below the present limits, to developing more accurate and precise methods of measurement of employee exposure and job-related loss of hearing, and to improving methods of noise control in the underground environment.

2. NOISE EXPOSURE MEASUREMENT

The chief practical objective of noise measurement is the determination of the exposure hazard of workers in the vicinity of a noise source. Once the degree of hazard has been reliably established it is possible to recommend proper control methods, if necessary, to reduce the noise exposure to an acceptable level.

Accurate noise level measurements can only be made using high quality instrumentation and proper measuring techniques (6, 8). For most purposes, the essential instruments are a good microphone, a high-quality sound level meter, and an accurate calibrator. The calibrator, which should be provided with a certificate of calibration, is required to check the adjustment of the sound level meter before and after each set of readings, because it is not unusual for the meter to drift by 1 or 2 decibels in a day. Such an error, if uncorrected, can result in serious inaccuracy (either high or low) in the result of a noise survey (4, 5, 6, 8, 10).

Because noise exposure limits are based on the time of exposure at each noise level (Table 2), the evaluation of the exposure hazard requires the measurement of the duration of each noise level. This may be approximated with an ordinary watch equipped with a sweep second hand, but for accurate results a stopwatch should be used.

After adjustment of the noise level meter using the calibrator, the microphone is connected to the meter and fixed in the position at which the noise level is to be observed. This is often as close as possible to the employee's ear, but it may be at an equal distance (often 1 metre) from both his ear and the noise source, or at some other suitable location depending on the circumstances. The sound pressure levels are noted using the A-weighting network and slow response settings of the noise level meter, and the duration of each level is measured using the stopwatch.

When the measurements are completed, the data are sorted according to sound pressure level and the total time at each SPL (90, 91, 92, ..., 115, > 115 dBA) is calculated. The sum of the times is obtained for each SPL interval given in Table 2, and these values are compared with the corresponding exposure limits to give the exposure coefficient (5).

Reading and recording the data manually will be very demanding, and great care must be taken to avoid errors, particularly if the noise level varies rapidly and frequently, as is often the case.

A strip chart recorder or magnetic tape recorder (the latter may be quite expensive) provides a permanent record of the variations in noise level and the duration at each level, which can be analyzed later in the laboratory. This eliminates the need to record the data manually, and reduces the possibility of error in reading or recording results.

It also permits collection of routine data by a single technician (4, 5, 6, 8, 12), although an assistant may be required to set up the apparatus or for special measurements.

Other instruments which may be used for noise exposure measurement include noise dosimeters and classifiers (6, 8, 12, 13). A wide variety of dosimeters are available with slightly different capabilities, but all of them are basically able to measure the duration of noise at each level as a fraction of the maximum permissible time at that level (cf. Table 2), eliminating the need for manual timing with a stopwatch. (The maximum exposure limits are built into the instrument electronically.) The total (sum of all fractions), which is the OSHA coefficient, is recorded and may be read at the end of the measurement period; it if exceeds the permissible limit (1.00 for a full 8-hour work shift), an overexposure has occurred. However, no record is available of the details of the noise exposure. The time cannot be established at which the excessive exposure occurred, and it cannot be determined whether the overexposure was caused by high noise levels for short periods, or by lower levels for longer periods. These factors may be very important in diagnosing the causes of the overexposure and devising proper corrective measures (5, 6, 8, 12, 13).

The disadvantages of noise dosimeters are partially eliminated by use of a noise classifier. This is capable of measuring and recording the duration of noise at each level. At the end of the measurement period, the recorded times are compared with the permissible limits at the corresponding noise levels (Table 2) to calculate the exposure coefficient (cf. Table 3). However, this instrument, like the dosimeter, is incapable of recording the time at which the excessive exposure occurred.

In order to characterize a noise source as completely as possible, it may be necessary to perform an analysis of the sound frequencies in the noise spectrum (octave band analysis). This usually consists in measuring the SPL in nine octave bands with centre frequencies given in Table 1. These data are often required to diagnose the sources of high noise levels, especially where several noise sources contribute to the total, and to enable the design of proper control devices or the redesign of equipment so as to reduce the noise emission at the source.

To obtain the most accurate noise exposure data, many factors must be considered which may affect the meter readings, and the techniques used must be designed to eliminate, reduce to a minimum, or compensate for these effects (4, 5, 6, 7, 8, 13). Some of these factors are environmental conditions such as temperature, pressure, and relative humidity (which may affect some types of microphone), directivity effects (which are inherent in many microphones and may also characterize some noise sources), proximity of sound reflecting surfaces, background noise levels, microphonics (caused by vibrations due to heavy equipment operation or very high sound pressure levels), and wind noise. Details of the proper measurement procedures to adopt in cases where these effects are suspected are best obtained by consulting a qualified noise expert, or (at least) a good textbook (e. g. 8).

It is most important that the microphone used in underground noise level measurements be carefully selected (6). In particular, the high relative humidity that is often found underground must be considered, as this will seriously affect the performance of some types of microphone. The directivity of the microphone must also be taken into account. Temperature effects are less critical, unless the microphone must be used on surface during winter. Probably the most suitable is an omnidirectional ceramic or piezoelectric type (lead zirconate-titanate, barium titanate or quartz) which has a flat frequency response, good temperature range, relative humidity range up to 100%, and an operating range up to 150 dB.

The usual practice in measuring noise levels has been to hold the sound level meter and microphone in one hand, and the stopwatch in the other. An assistant is then required to record the results, and it has proven to be difficult or impossible to make measurements safely underground on or near moving machinery. To overcome these problems a special tripod-mounted extension holder for the microphone was developed in the Elliot Lake Laboratory (5) which enables the mounting of the microphone in the proper position without interfering with work in progress. If the noise level meter is also tripod-mounted the operator's hands are freed for operation of the stopwatch and recording data and notes. This is a great advantage because, in the absence of a recording instrument, a considerable amount of data must be recorded manually to provide a reliable estimate of noise exposure (5, 12, 13).

In an effort to reduce the time and effort required for collection of data and calculation of noise exposure coefficients when noise levels vary over a wide range with frequent and rapid changes (as is usual in underground mines), the use of a strip-chart recorder with a sound level meter to record underground noise levels has been simulated at the Elliot Lake Laboratory (12). Exposure time at each sound pressure level was obtained underground and the data transferred to a typical strip chart. The chart record was then analyzed by means of a simple mechanical integrator. The combined exposure times for each noise level were then used to calculate the OSHA exposure coefficient. It was found that this graphical technique could afford an appreciable saving of time in estimating the exposure compared to the usual method, without any significant loss of accuracy. Moreover, the procedure can readily be learned by anyone with a minimum of technical training; it does not require an expert acoustician, and it has been suggested for routine use in Canadian mines.

3. NOISE CONTROL AND ABATEMENT

Data collected in field studies at the Elliot Lake Laboratory (5, 12, 13) have shown that noise levels in underground Canadian mining operations reach 115 dBA or more in some cases, as indicated in Table 4. These measurements were made with a sound pressure level meter using the A-weighting, slow response settings, and have been corrected for background noise* where necessary (4). Except where it is noted, observations were taken at the equipment operator's ear. (The use of proper ear protection, i. e. ear plugs or muffs, by the operator is mandatory in these high noise level operations.) Where more than one value is given, the results were obtained either for two pieces of equipment, or on two separate days. All data are given as the mean and the standard deviation of the mean, i. e. standard error (14).** It is apparent that the mean sound pressure levels are fairly consistent for a given location or operation, except for some pieces of LHD equipment which have noise levels that seem to depend on the operating conditions, or on the age and mechanical condition of the equipment. The latter factors were examined further (13), in tests with the vehicle stationary, and the engine either idling or with wide open throttle. Sound pressure levels at the operator's ear varied from 80 to 94 dBA with the engine idling for a variety of old and new trucks, scoop trams, bulldozers, and man carriers. At full throttle, the range was also wide, from 92 to 107 dBA.

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* The general noise level when the equipment is not operating.

** The data are the mean sound pressure levels during machine operation, not during the full shift.

TABLE 4

Sound Pressure Levels in Various Locations and for Various Underground Mining Operations (9, 13)

Location/Operation	Mean Sound Pressure Level dBA	Sound Pressure Level Range dBA	No. of Measurements
Lamp room *	65.0 ± 1.3	62 - 68	11
	64.5 ± 0.3	60 - 70	41
Shaft *	73.0 ± 1.0	65 - 86	37
	72.8 ± 0.4	63 - 88	258
U/G shaft station, w cage*	87.7 ± 0.4	86 - 89	7
" w/o cage*	94.2 ± 0.3	92 - 97	21
Truck station*	80.7 ± 0.3	80 - 82	7
Unimog man carrier, upgrade (in back of truck)	97.3 ± 0.4	87 - 112	191
	99.0 ± 0.2	85 - 112	401
Unimog man carrier, downgrade (in back of truck)	93.9 ± 1.3	88 - 98	7
	98.4 ± 0.5	78 - 108	106
Unimog man carrier, level, 24 panel	101.6 ± 0.4	95 - 104	29
Unimog man carrier, downgrade	101.2 ± 0.4	94 - 101	28
Crusher	100.0 ± 0.3	90 - 111	170
	98.7 ± 0.3	92 - 112	190
Breaker	99.8 ± 0.3	90 - 112	157
Airleg Drill	111.5 ± 0.3	96 - 118	154
Heavy drifter	112.7 ± 0.4	90 - 117	92
	112.2 ± 0.2	91 - 117	194
Jumbo three-boom drill	116.3 ± 0.4	93 - 120	163

* In general area.

Table 4, continued

Location/Operation	Mean Sound Pressure Level dBA	Sound Pressure Level Range dBA	No. of Measurements
MTT-420 Teletram,** loaded	105.0 ± 0.8	--	6
MTT-420 Teletram, ** empty	103.0 ± 0.4	--	6
ST-5 Scooptram, ** loaded	102	--	2
ST-5 Scooptram, ** empty	101	--	2
D-6 Bulldozer **	96 ± 1.2	--	2
Land Rover **	91	--	3
Cline Truck, loaded**	102.5 ± 0.7	--	6
Cline Truck, empty**	100 ± 1.5	--	6

** Beside moving vehicle.

Table 4 includes most major operational sources of noise exposure, and particularly those which require the presence of an operator. They are typical, therefore, of the most probable major contributors to an employee's cumulative exposure. There are, in addition, other sources of employee noise exposure. One such source is the ventilating fans which are necessary to provide adequate fresh air in the underground work places. Tests have been made of the sound pressure level (dBA, slow response) for various fans, as indicated in Table 5 (13). Unless otherwise noted, measurements were made at a distance of 1 metre perpendicular to the axis of the fan.

Several general conclusions may be based on the data in Table 5. It is immediately apparent that large diameter, high capacity fans have significantly higher noise levels than small diameter, lower capacity fans. Silencers often have an appreciable effect in reducing noise levels, and other data indicate that they do not significantly reduce efficiency nor increase power consumption. Centrifugal fans appear to be slightly less noisy than axial, and axial/centrifugal fans seem to be appreciably quieter than either axial or centrifugal types. The fans listed in Table 5 were supplied by different manufacturers, and the observations indicate that there is little or no correlation between manufacturer and noise level. However, this conclusion may not remain valid in the future because fan manufacturers are continually improving the design and construction of their products, including their noise emission characteristics.

TABLE 5

Typical Noise Levels for Underground Ventilation Fans

Fan Type	Diameter (cm)	Capacity (m^3/min)	SPL (dBA)	Remarks
Axial	366	15000	111	On axis, 10 m downstream
Axial	274	9350	105	"
Axial	244	9060	104	"
Axial	183	3970	102	On axis, 10 m upstream
Axial	122	990	88-90	
Axial	122	1500	90	
Axial	76	510	96	
Axial	76	710	101	
Axial	61	280	95	Silencer
Axial	61	280	98	2 fans in ‖; distance 2 m
Axial	61	280	99	On axis, 1 m
Axial	61	280	98	
Axial	61	280	90	Silencer
Axial	48	170	97	
Centrifugal	135-B*	85	94-95	
Ax/Cent	800 MF*	540	92-93	
Ax/Cent	800 MF*	--	94	2 fans in series

* Fan type or model.

As a general rule, employees are not required by their duties to work for appreciable periods in the immediate vicinity of fans, particularly those of large capacity. Nevertheless, supervisory staff must always keep in mind the potential hazard in the exceptional or occasional case when a worker spends an appreciable fraction of his time close to a ventilating fan. This applies particularly to service staff (carpenters, electricians, pipe-fitters, etc.) who may have to be provided with hearing protection in such cases.

4. CONCLUSIONS

The necessity for control of noise exposure in underground Canadian mines is well illustrated by the data presented above. Similar data could be obtained in other locations, and would provide a basis for recommending suitable control measures. The major difficulty lies in the decisions that must be taken to assure that employee's exposures are controlled at a safe level.

The techniques that are presently recognized as suitable for control of noise exposure fall into three categories: limitation of noise emission, provision of adequate hearing protection equipment, and administrative control of exposure. Most authorities agree that limitation of noise emission ought to be regarded as the most important and effective method, although it is probably more difficult and more expensive, and requires more time. It includes such procedures as redesign of existing equipment, development of completely new equipment, addition of mufflers or silencers to equipment, and surrounding the noise source with a sound-proof enclosure. For a variety of technical, practical, and economic reasons, these methods probably represent long-term solutions for the average underground Canadian mine. Nevertheless, mine operators and equipment suppliers should be encouraged to pursue this goal as vigourously as possible.

Provision of hearing protection equipment should only be considered a temporary alternative to limitation of noise emission. However, if it is found to be necessary, the advice of an audiometric technician should be sought before any decisions are reached as to the type of protective equipment that is required (8, 11). There is a wide variety of protective equipment available, and the claims made for its effectiveness may be very confusing and misleading. Although good ear plugs may be adequate in one instance, ear muffs may be necessary in another, and both plugs and muffs in a third. Moreover, hearing protective equipment is only effective if it is properly fitted and if the employee is trained in its use. This should be done initially by a qualified technologist, and follow-up in the proper use of the equipment must be made the responsibility of suitably trained supervisory staff. If this follow-up is not done carefully and constantly, familiarity or minor discomfort due to improper use may lead to carelessness and indifference and finally, complete ineffectiveness of the protective equipment. Properly used equipment, on the other hand, can be highly effective in reducing noise exposure and preventing permanent hearing loss.

As a last resort, when noise emission cannot be limited and even hearing protection proves inadequate, administrative control may be attempted. This means simply that each employee's exposure is carefully monitored, and he is rotated to a quiet job when his exposure limit is reached. This control procedure has been adopted as standard practice, and has worked well, in the case of the nuclear industry whenever employees are exposed to high radiation fields. Nevertheless, it has only been used if the source of radiation cannot be shielded adequately, because of the administrative problems of proper record-keeping and of finding suitable employment for rotated employees, and the possibility of an inadvertent overexposure because of a breakdown in the system. For all these reasons, this system ought to be attempted for noise exposure control only when all else fails, or to supplement other methods.

Noise control programs should include periodic medical surveys by an otolaryngologist in order to determine the degree of hearing loss, if any, suffered by workers, and to establish whether this loss exceeds the normal loss which occurs as a result of aging. Such medical data can provide protection for the employer in the case of an unjustified claim, or supporting evidence for the employee in validating a job-related loss of hearing.

Work is continuing at the Elliot Lake Laboratory on the development of improved and simplified techniques for noise exposure evaluation in Canadian mines, and on the collection of reliable noise level data. This will enable technical advice and assistance to be made available on request to mine management and staff concerning noise exposure control procedures, and to equipment suppliers concerning design modifications to reduce noise emission.

At present, the most urgent need is for reliable noise level data from a broad cross-section of mining operations, in order to apprise mine management and staff of the extent of the noise control problem. Later, such data can provide a basis for more detailed analysis of noise problems or for designing more sophisticated studies, if required. The techniques and data outlined in this paper will, it is hoped, form a useful guide for mining technologists who may be required to collect the basic data needed to evaluate noise exposure levels in underground Canadian mines.

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An acoustical method for source location of methane

1980

MÉTHODE ACCOUSTIQUE POUR DÉTERMINER LES SOURCES DE MÉTHANE

par

M. Savich*

RÉSUMÉ

Dans presque le tiers des mines de la Hongrie qui se trouvent dans des formations oligomiocènes (époque tertiaire), la teneur en méthane est dangereuse pour les travailleurs qui y sont exposés.

Le méthane s'accumule dans des couches de charbon, causant une montée de pression considérable qui produit des vibrations accoustiques détectées par des accéléromètres sensibles. Ce système de détection est supérieur du fait que la détection peut être faite à partir de la surface.

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AN ACOUSTICAL METHOD FOR SOURCE LOCATION OF METHANE

by

M. Savich*

ABSTRACT

Almost one-third of Hungarian mines in Oligomiocene formation (an epoch of the Tertiary formation) have methane in quantities dangerous to workers exposed to this gas.

Methane accumulates in coal strata, thereby causing great pressure build-ups. The pressure induces the production of acoustic emissions detected by sensitive accelerometers. This system is superior because detection can be made from the surface.

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INTRODUCTION

During the XVIII International Conference* on Scientific Research in the Field of Safety at Work in the Mining Industry, discussion was focused also on methane. The Hungarian delegation announced that a project was under way in their country to make early detection of methane possible before it could spread throughout the mine. No details were available, except that the project was being carried out under the auspices of the Central Mining Institute (Központi Bányászati Fejlestési Infézet) in Budapest. This was the necessary impetus for me to pay closer attention to this problem.

Often in American journals there are announcements of ambitious programs destined to increase coal production in Hungarian mines. Nearly one-third of the mines in Oligomiocene (an epoch of the Tertiary) formations contain methane in dangerous quantities. One of the most dangerous mines in this respect is Pecs, on the Yugoslavian border. Because of impermissible methane levels, preventive blasting with 120 m long boreholes is being done. Further research is being done with acoustic emission from methane activity.

ACOUSTIC EMISSION INTERPRETATION OF METHANE IN THE COAL

During a three-day (March 18-20) Brüel & Kjaer seminar and workshop session in Montreal, it was revealed that early detection of methane in Hungarian mines was being done with B & K instruments.

PROPERTIES OF COAL AND ROCK NOISE

Because of accumulating methane, high pressure forms in coal strata, thus causing acoustic emission. This is why early detection is possible (Fig. 1).

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* Cavtat (Dubrovnik), 7-14 October, 1979.

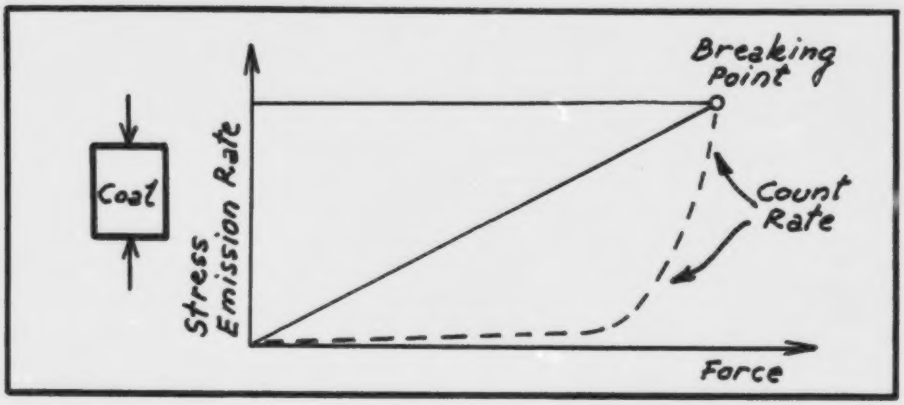

Fig. 1: Low frequency acoustic emission for mine protection.

THE BASIC SYSTEM FUNCTION

The system consists of three major components connected together (Fig. 2):

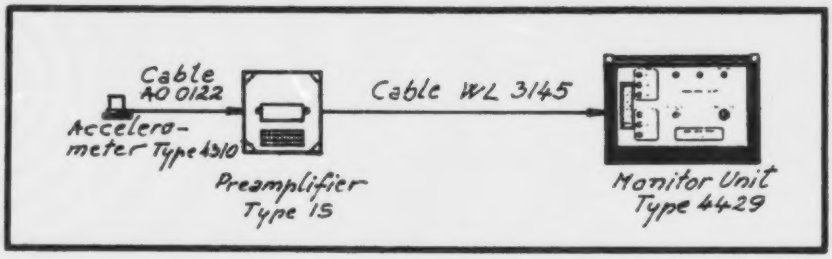
Cable A0 0122
Accelerometer Type 4370
Preamplifier Type IS
Cable WL 3145
Monitor Unit Type 4429

Fig. 2: Preamplifier mounted near accelerometer and the remote monitor unit.

1) Accelerometer, Type 4370, with sensitivity normalized to 10*pC/^{1}ms^{-2} (C - coulomb).

It should be noted that the accelerometer must be well coupled to the rock, in a hole 3-5 m deep, to facilitate good wave arrivals. The hole must be extremely dry before mounting the accelerometer.

2) Preamplifier Type IS ("Hungarian Type", especially developed for Hungary), with sensitivity adjustment potentiometer (0.9 mV/pC) and a frequency range of 1 Hz to 200 kHz.

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* Also have Uni-Gain ® sensitivity to ± 2%.

3) Vibration Monitor, Type 4429, for permanent installation in monitoring systems.

This system can be employed where the vibrational or electromagnetic environment prohibits the use of long cables between accelerometer and monitor, where too much noise is picked up.

PRACTICAL APPLICATION

The schematic of a mine shows a way to install accelerometers to detect methane (Fig. 3).

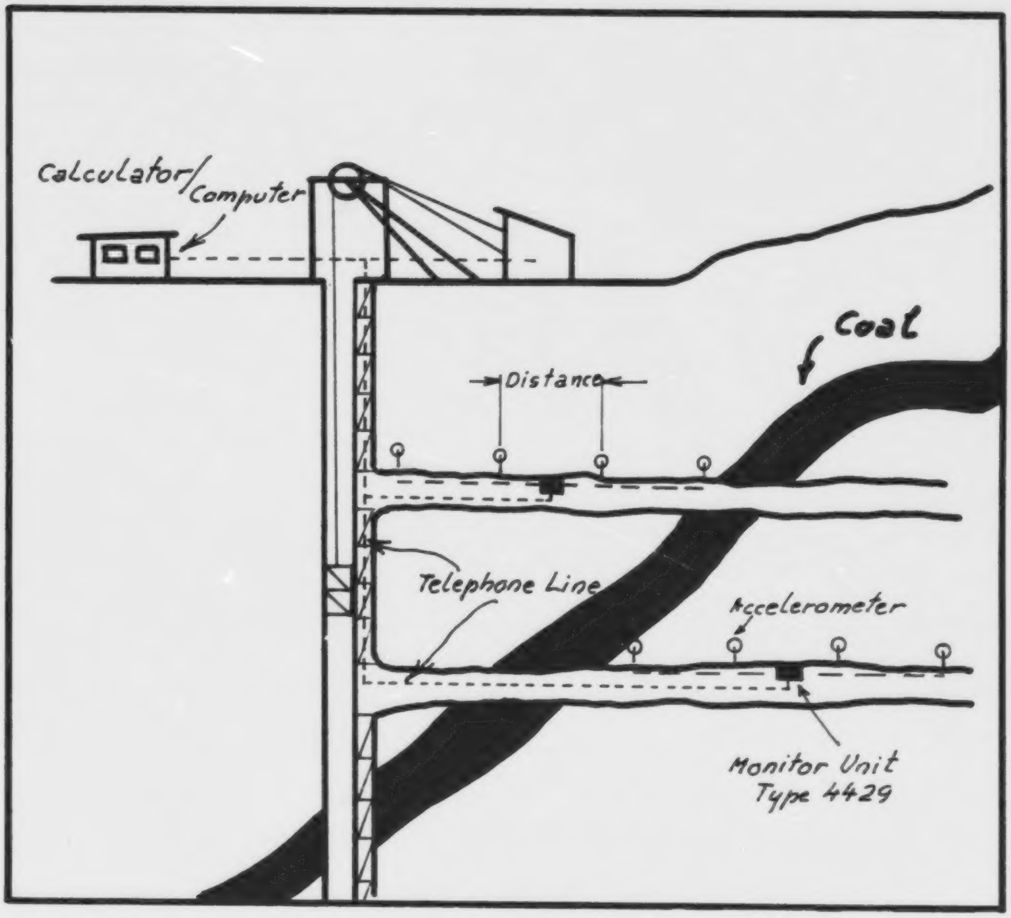
Calculator/Computer
Coal
Distance
Telephone Line
Accelerometer
Monitor Unit Type 4429

Fig. 3: Low frequency transducers for long range detection in mines.

Distances between accelerometers are arrived at experimentally. For high frequencies, installing accelerometers closer together is better. The 5 kHz components are transmitted over 100 to 300 meters, depending on rock qualities. These frequencies are high enough not to be disturbed by usual mine traffic; however, the system must be disconnected during blasting.

Due to a high increase in count rate at the limit, more transducers (four) may be connected to each channel of 4429. These systems can also initiate an automatic shutdown sequence to prevent further deterioration, and they can operate an alarm system (1). The three stage indication can be made available at a remote reading and control station, which permits connection to an on-line computer for an integrated monitor and control system on the surface. Telephone lines can be used also.

SPECIFICATIONS AND PRICE LISTINGS

In Fig. 4 is a basic scheme with 4 transducers and a precise description.

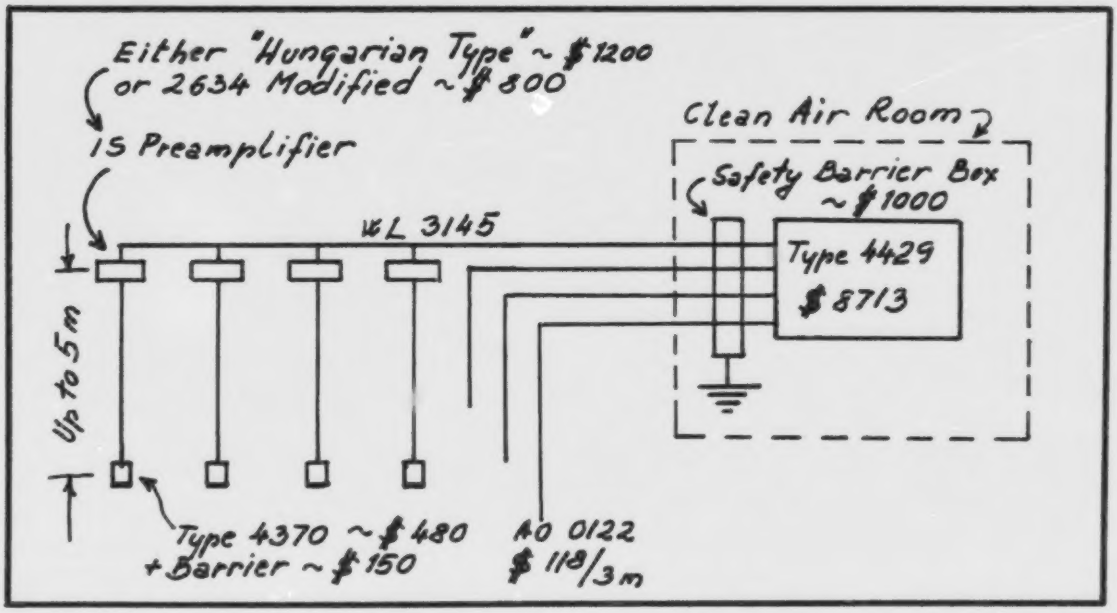
Either "Hungarian Type" ~ $ 1200
or 2634 Modified ~ $ 800
IS Preamplifier
Clean Air Room
Safety Barrier Box ~ $ 1000
WL 3145
Type 4429
$ 8713
Up to 5 m
Type 4370 ~ $ 480
+ Barrier ~ $ 150
AO 0122
$ 118/3m

Fig. 4: Basic unit for detecting stress concentration.

1)	Accelerometer 4370	4 pieces at $480	$1,920.00
	IS barrier	4 pieces at $150	$ 600.00
2)	Cable AO 0122 (3 m = $118)	4 pieces at $118	$ 472.00
3)	IS preamplifier:		
	"Hungarian Type"	4 pieces at $1,200	$4,800.00
	(or Type 2634 Modified	4 pieces at $ 800	$3,200.00
4)	Low noise transducer cable WL 3145		~ $1,800.00
5)	Monitor unit		$8,713.00
6)	Barrier box		$1,000.00
			$19,305.00

Each further addition of accelerometers (four) requires a further investment of $7,792.00. The main task, if this project comes to fruition, should be to increase the lifetime of accelerometers.

STRESS-CONCENTRATION LOCATION TECHNIQUES

The direct method, if possible, is best. With methane accumulation in coal strata, surely the system becomes more complex. To obtain precise daily information on source-locations of rock noise, many more parameters must be taken into consideration: surface and subterranean traffic, machines, compressors, exploration, different kinds of stress, etc. The experience that the U.S. Bureau of Mines has had can be used effectively here (2)(3).

CONCLUSIONS

1) The exhibited system for early detection of methane can be applied to some gassy mines in Alberta and Nova Scotia.
2) The combined experimental and numerical technique should be applied. It seems to be an efficient method for early methane detection, when that methane has accumulated in coal strata.

3) The best choice depends on structural geology, the wave force spectrum and on computer availability. The applications will be used to interpret results and predict the effects of methane accumulation characteristics and operating strategy on field performance.

ACKNOWLEDGEMENTS

Hans Maersk-Moller, a specialist on transducers and instrumentation for machine maintenance and monitoring at Brüel and Kjaer, has made considerable contributions in solving low frequency acoustic emission for mine protection.

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Combustion - noise and

Vibration research projects

1982

PROJET DE RECHERCHE SUR LE BRUIT ET LES VIBRATIONS DE COMBUSTION DES MOTEURS

par

M.U. Savich*

RÉSUMÉ

Le bruit produit par les véhicules miniers a un effet des plus néfastes sur l'environnement souterrain. Les véhicules les plus utilisés sont les chargeuses-transporteuses.

Comme le carburant est de plus en plus rare et coûteux, les moteurs diesels devront peut-être être alimentés avec des carburants à faible indice de cétane. Une réduction de 53,3 à 36,3 de l'indice de cétane a produit une augmentation de 4,5 dBA du bruit de combustion produit par un moteur de camion type. Si l'emploi du moteur diesel doit se généraliser dans les mines, il faut que le bruit et les vibrations qu'il produit ne dépassent pas un niveau acceptable, quelles que soient les exigences en matière de réduction de l'ensemble des bruits des véhicules.

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Les règlements sur le bruit appliqués au Canada, à l'exception de la Colombie-Britannique, étaient ceux adoptés par l'OSHA. La Colombie-Britannique appliquait la norme internationale R1999.

Le bruit se propage à partir des surfaces externes du moteur qui vibre sous l'effet des forces qui s'y exercent. Ce bruit est causé par la combustion et l'impact des pistons et du pignon de distribution.

Tous les travaux de recherche et de mesure seront effectués dans le laboratoire (à l'intérieur et à l'extérieur) et dans la mine souterraine.

Le problème le plus difficile à résoudre est la réduction du bruit de surface du moteur. Le bruit du moteur doit être réduit de plus de 10 dBA pour satisfaire aux exigences de l'OSHA. Il existe une relation causale entre le bruit et les vibrations. Il existe, en général, trois façons fondamentales d'atténuer le bruit de combustion :

- réduire le délai d'allumage;
- diminuer le carburant injecté durant le délai d'allumage; et
- limiter le mélange carburé durant le délai.

Tout changement à apporter au système de combustion pour réduire le bruit aura un effet sur d'autres aspects du rendement du système de combustion, soit la fumée, la consommation de carburant et les émissions d'oxyde d'azote et d'hydrocarbures non brûlés. Ce projet de recherche soulèvera, par conséquent, de nombreuses difficultés.

Les sommes totales investies dans les instruments de mesure du bruit et des vibrations s'élèvent à 122 334,00 $.

COMBUSTION - NOISE AND VIBRATION RESEARCH PROJECT

by

M.U. Savich*

ABSTRACT

Noise from mining vehicles has a most pervasive influence on the underground environment. The most used machines are the load-haul-dump (LHD) vehicles.

As a result of fuel becoming scarce and more expensive, diesel engines may be required to run on fuels with low cetane numbers. A reduction from 53.3 CN to 36.3 CN produced a 4.5 dBA increase in combustion noise from a typical truck engine. If the diesel engine is to become more widely used in mines to propel vehicles, there is a need to make noise and vibration from diesel engines more acceptable, apart from the requirements to reduce overall levels to bring the total vehicle noise below limits submitted in legislation.

The noise regulations used in Canada, excepting British Columbia, are those adopted by the OSHA. British Columbia used International Standard R1999.

Noise is radiated from external surfaces of the engine as they vibrate in response to the forces developed within the engine. The noise radiated by the engine surfaces originates from combustion, piston and timing gear impacts.

All research and measurements will be performed in the laboratory (indoors and outdoors) and underground in the mine.

The most difficult problem is to reduce the engine surface noise. The engine noise requires a reduction of more than 10 dBA, to meet OSHA requirements. The noise and vibration are in causal connection. In general

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there are three basic ways to reduce combustion noise:

- reduce ignition delay period;
- reduce fuel injected in the ignition delay period; and
- restrict air/fuel mixing during the delay period.

Any changes made to combustion system to reduce noise will affect other aspects of combustion system performance - smoke, fuel consumption and emissions of nitrogen oxides and unburnt hydrocarbons. The research will be very difficult.

Total investment in noise and vibration instruments is $122,334.00.

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INTRODUCTION

NUISANCE

Noise from mining vehicles has a most pervasive influence on the underground environment. The results of a survey of noise in mines showed that noise from mining traffic disturbed far more workers than noise from any other source in the mines. The most used machines are the load-haul-dump (LHD) vehicle. For the most part the vehicles used for underground mining operations are powered by engines with more than 130 hp. The machine, as a source, does not produce a continuous noise. The noise varies from one day to the next and therefore from one site to the next. The operators and bystanders are exposed to these variable sound sources.

In order to illustrate the effects of noise exposure index of different machines, Table 1 was completed.

NOISE CONTROL THROUGH COMBUSTION EFFICIENCY

As a result of fuel becoming scarce and more expensive, diesel engines may be required to run on fuels with low cetane numbers. A reduction from 53.3 CN to 36.3 CN produced a 4.5 dBA increase in combustion noise from a typical truck enginer (1). Less extreme reductions to 40 or 45 CN are likely to increase combustion noise by 2 to 3 dBA. These increases in sound level may not appear to be very significant, but the impulsive character in sound emitted will be accentuated. Investigations into complaints of noise from industrial premises show that most complaints concern noise with strong impulsive or tonal characteristics. It seems likely, therefore, that degradation of the fuel will cause more disturbance than the increase in noise level would seem to indicate.

If the diesel engine is to become more widely used in mines to

Table 1 - Noise of different vehicles

No.	Vehicle Type and Manufacturer	L_{eq}* (dBA)	Note
1	MTT-420 Teletram Wagner	100.5	175 hp
2	ST5A Scooptram Wagner	100.5	175 hp
3	ST4A Scooptram Wagner	105.6	145 hp
4	ST2B Scooptram Wagner	98	78 hp
5	966C Loader Caterpiller	99	130 hp
6	D4D Bulldozer Caterpiller	98.5	56 hp
7	Monashee - Wagner	98.6	52 hp
8	Service Truck - Wagner	98.6	52 hp
9	Development Jumbo-Wagner	98.6	52 hp
	Logarithmic Average	100.54	

propel vehicles, there is a need to make noise and vibration from diesel engines more acceptable, apart from the requirements to reduce overall levels to bring the total vehicle noise below limits submitted in legislation. The worker must see and hear everything, so that he may work undisturbed and escape dangerous conditions.

REGULATIONS AND STANDARDS

Proposed new CSA Standard Z107.32, Test Procedure for the Determination of Exterior and From Construction, Forest and Mining Machines, has been introduced. This test procedure was written specifically to provide a Canadian test procedure which harmonizes with the intent of the EEC (Common Market) procedure contained in the Official Journal of European Communities (Ref. document EEC 79/113), International Organization for Standardization documents ISO 4872 and ISO/DIS 6393, and SAEJ919 SEP 80 - Sound Measurement - Earthmoving Machinery - Operator - Singular Type.

The EEC and ISO documents basically converted ISO 4872-1978 into a sound power test procedure for earthmoving machines, to be adopted by all EEC member countries. Some experts wanted the procedure to be of the complexity of conducting dynamic tests, dynamic "sound power" tests have been held in abeyance.

This proposed CSA document covers a broader range of construction, forestry and mining machinery because Canadian export. The mining machine industry and research have to support development and create a positive environment for advancement to provide solutions to our most pressing problems: to become effective, economical and environmentally acceptable, and more competitive in world market(2).

For the operator sound this test procedure has been cross-referenced to SAEJ919 SEP 80 - Sound Measurement - Earthmoving Machinery - Operator -

Singular Type. The SAEJ919 SEP 80 was endorsed for use in Canada by the working group and sub-committee.

The regulations presently used in Canada, excepting British Columbia, are those adopted by the OSHA, for example, which permit a worker to be exposed to a noise level of 90 dBA for 8 h/day and require dividing in half the permissible exposure time for each 5 dBA increase in noise level. British Columbia has an exchange rate of 3 dB increase for halving of duration (ISO R 1999).

Table 2 shows the existing, future and possible long-term limits for vehicles in Western European Countries, and Table 3 shows the same information for North America.

NOISE AND VIBRATION BY DIESEL ENGINES

Noise is radiated from external surfaces of the engine as they vibrate in response to the forces developed within the engine. Figure 1 summarizes the structure response of the engine in terms of those parts which respond most strongly to the various exciting forces (Lucas CAV Limited).

Most of the noise radiated by the engine surfaces originates from:

1) Combustion noise: compression, combustion and expansion pressure transients developed in the cylinder. The combustion noise was studied in detail by Priede (3, 4);
2) Piston slap: impacts between piston and cylinder wall, as the piston moves from side-to-side during the engine cycle. Piston slap has been studied by several groups of research workers (5 to 11);
3) Timing gear impacts: impacts between timing gear teeth, as backlash is taken up in either direction in response to crankshaft torsional vibration and the fluctuating torque requirements of the camshaft and the fuel injection equipment (12).

Table 2 - Noise limits proposed for west European countries.
Test modified R362 (R177 or similar) at 7.5 meters.

Category	Maximum Permissible Noise Level in dB(A) at 7.5 m		
	(Now)	After Oct. 1982 EEC Directive 212	After Oct. 1985/8 (Future Possible)
Truck > 3.5 Mg < 149 kW	89	86	(80)
Truck > 149 kW	91	88	(80)

Table 3 - Noise limits proposed for USA (test J366b) at 50 ft.

Category	Maximum Permissible Noise Level in dB(A) at 15.23 m		
	1980 (Now)	After 1982 (Future Definite)	After 1985 (Future Possible)
Medium and Heavy trucks > 10,000 16 GVW at 50 ft. (test J366B)	83	80 (Jan. 1, 1982)	(75?)
Buses at 50 ft. (test J366b)	83	80 (Jan. 1, 1983)	77
Buses Interior Noise (Noisiest Position)	86	83 (Jan. 1, 1983)	80

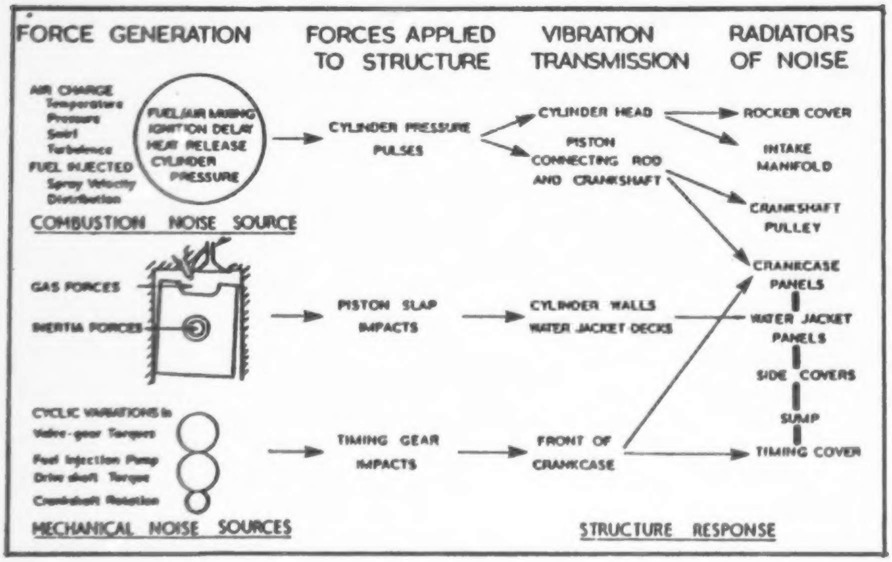
FORCE GENERATION
FORCES APPLIED TO STRUCTURE
VIBRATION TRANSMISSION
RADIATORS OF NOISE
AIR CHARGE
Temperature
Pressure
Swirl
Turbulence
FUEL INJECTED
Spray Velocity
Distribution
FUEL/AIR MIXING
IGNITION DELAY
HEAT RELEASE
CYLINDER PRESSURE
COMBUSTION NOISE SOURCE
CYLINDER PRESSURE PULSES
CYLINDER HEAD
PISTON CONNECTING ROD AND CRANKSHAFT
ROCKER COVER
INTAKE MANIFOLD
CRANKSHAFT PULLEY
CRANKCASE PANELS
GAS FORCES
INERTIA FORCES
PISTON SLAP IMPACTS
CYLINDER WALLS
WATER JACKET DECKS
WATER JACKET PANELS
SIDE COVERS
SUMP
CYCLIC VARIATIONS in
Valve-gear Torques
Fuel Injection Pump
Drive shaft Torque
Crankshaft Rotation
TIMING GEAR IMPACTS
FRONT OF CRANKCASE
TIMING COVER
MECHANICAL NOISE SOURCES
STRUCTURE RESPONSE

Fig. 1 - Noise and vibration from diesel engines (Lucas CAV Limited)

Vibration measurements will be made at a grid of accelerometer positions on the engine surface and at operator's seat.

Tyre noise has been studied all over the world with the object of reaching an understanding of the mechanism of tyre noise and of specifying a tyre design for the quite heavy vehicle which would meet the target noise level of 77 dBA.

All measurements will be performed in laboratory (indoors and out doors) and underground in mines.

LABORATORY MEASUREMENT

INDOORS

The measurement method of engine noise should be as reliable and as simple as possible, consistent with giving results which are representative of the noise emission properties of engines.

The existing procedures for rating the noise emitted by engines are in numerous national and international noise measurement procedures (13 to 17). The results obtained vary significantly with procedure used, and not all procedures offer the means for determining sound power.

Measurements on 3 metre radius hemisphere and at 1 metre (front, top and two sides) are recommended. From both methods, sound power can be determined simply and with good accuracy (Fig. 2)(18).

Calculation of Sound Power Level and Directivity Index from microphones positioned on the surface of a 3 metre radius hemisphere is as follows:

$$SWL = SPL_A + 10 \text{ Log}_{10} 2\pi r^2 \text{ (dB)} \qquad \text{Eq 1}$$

where, SWL = Sound Power Level (dBre 1pW)

SPL_A = Average Sound Pressure Level (dBre 20 μPa)

$$= 10 \log_{10} \frac{1}{n} (\text{antilog}_{10} \frac{SPL_1}{10} + \text{---} \ \text{antilog}_{10} \frac{SPL_n}{10})$$

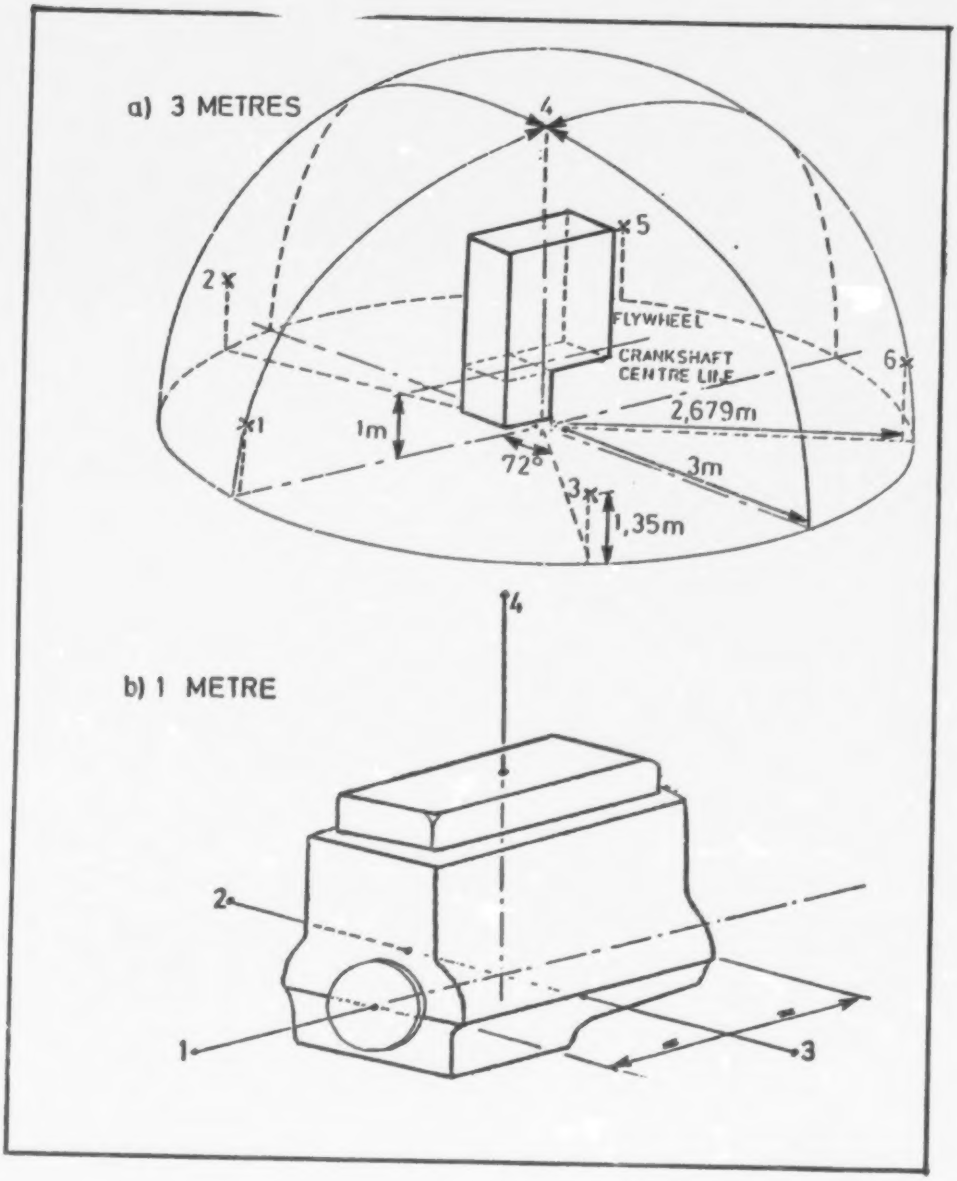
a) 3 METRES
4
5
2
FLYWHEEL
CRANKSHAFT CENTRE LINE
6
1
1m
2,679m
72°
3m
3
1,35m
b) 1 METRE
4
2
1
3

Fig. 2 - Microphone positions.

n = number of microphones

r = radius of hemisphere (m)

when, r = 3 meters

$$SWL = SPL_A + 17.5 \text{ (dB)}$$

(see development in reference 18)

and at 1 m measurements, the sound power level of an engine is given by adding 12.1 dB:

$$SWL = \text{Average SPL at 1 m} + 12.1 \text{ (dB)} \qquad \text{Eq 2}$$

The single figure rating is useful for comparing with intensity measurements and sound power from vibration measurements.

For sound (noise) measurement CANMET's instruments will be used and for vibration measurement Portable Vibrating Analyzer Type 3513 should be used (Fig. 3). The instrument is completed self-contained and intended for machine condition monitoring and the general study of mechanical vibration. The Vibration Meter measures displacement, velocity or acceleration in RMS or peak-to-peak values to conform to a variety of established machine vibration criteria. It can be set to the 10 to 1000 Hz frequency range for monitoring vibration severity in accordance with ISO national and industry standards. The tunable filter enables frequency analyses range 03 Hz to 15 kHz, and frequency analysis with wide and narrow band filter. Synchronization for semi-automatic frequency response plotting on CANMET's level recorder can be done.

Investment is: (duty included)

3513 Portable Vibration Analyzer 2511 Vibration meter 1621 Filter 4370 Accelerometer	$ 9,183.00
4370 Accelerometer	797.00
A00087 Cables	23.00
AQ0034 Cables to 2306 CANMET's Level Recorder	92.00
Casework	215.00
Total:	$10,310.00

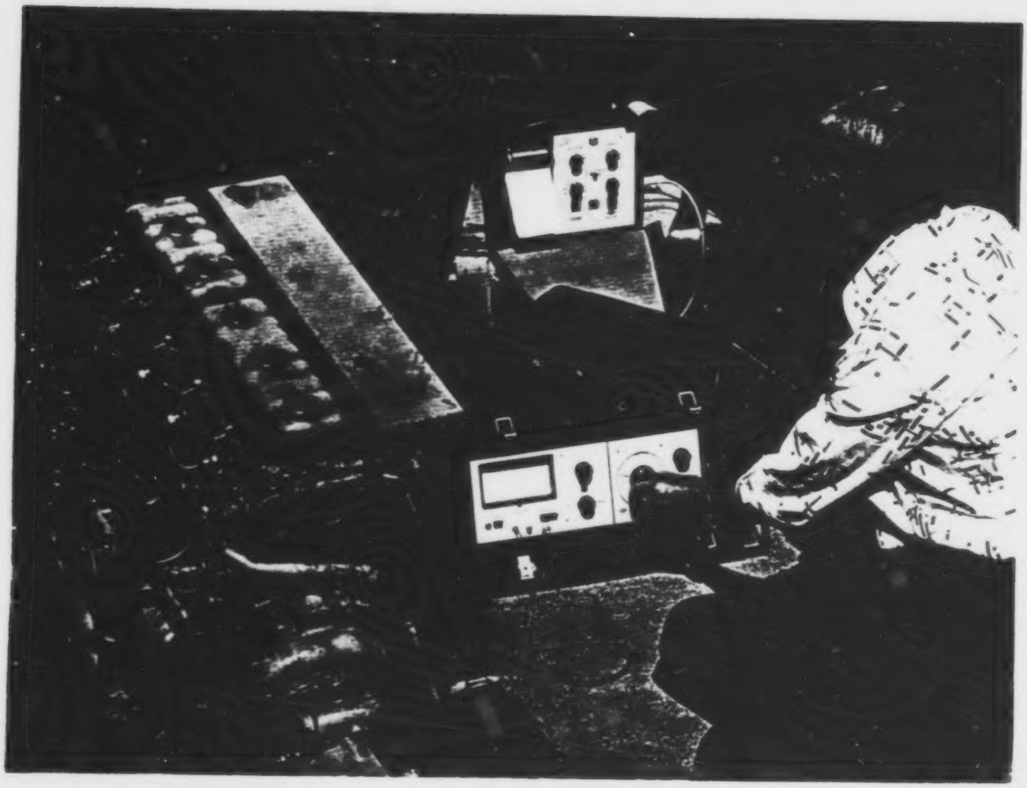

Fig. 3 - Measurement displacement, velocity or acceleration or peak-to-peak values on engine.

OUTDOORS

In this measurement, an important objective was the evaluation of the additional costs of quieting the final demonstration vehicle and the establishment of the variation in cost for various degrees of quieting.

Uniform test procedures are a key element in this measurement. Standard CSA sound level test procedures Z107.32 must be applied. The standard is proposed and specifies procedures for determining representative A-weighted sound levels exterior to the machine and in the operator's station. The microphone shall be positioned to coincide with the surface of a hemisphere enclosing the machine (Fig. 4). The radius of the hemisphere shall be determined by the machine length. All instruments for outdoor measurements are identical with underground measurements. In this study standards should be applied from references 19 to 34, only in the special cases.

UNDERGROUND MEASUREMENT

This is a fully automated system designed for seven days to retrieve sound pressure information from 3 channels and vibration information from 5 channels in an underground environment on mining vehicles (Fig. 5). Power is to be provided by one or more automobile batteries, and data is stored on a cassette tape in digital form, thus reducing the possibility of data loss through power drop-out.

SOUND (NOISE)

The purpose of this equipment is to correlate vehicle noise with noise dose to operator. This figure relates to operator fatigue and hearing loss. Further information will be gathered which will aid in reaching the noise target for the vehicle.

Sound pressure levels will be measured at 3 locations using type 4165

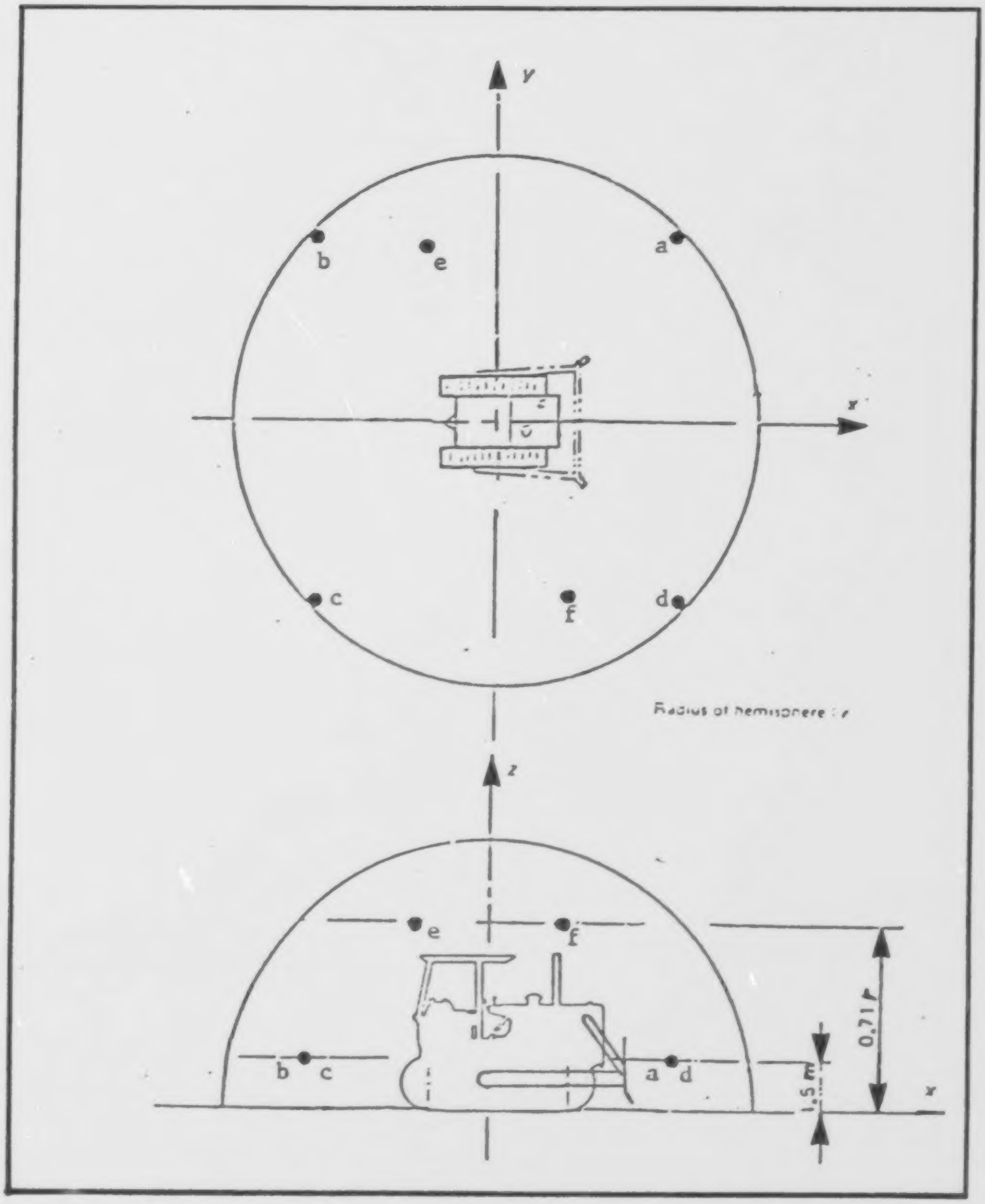
y
b
e
a
x
c
f
d
Radius of hemisphere : r
z
e
f
0.71 r
b
c
a
d
1.5 m
x

Fig. 4 - Microphone array on the hemisphere.

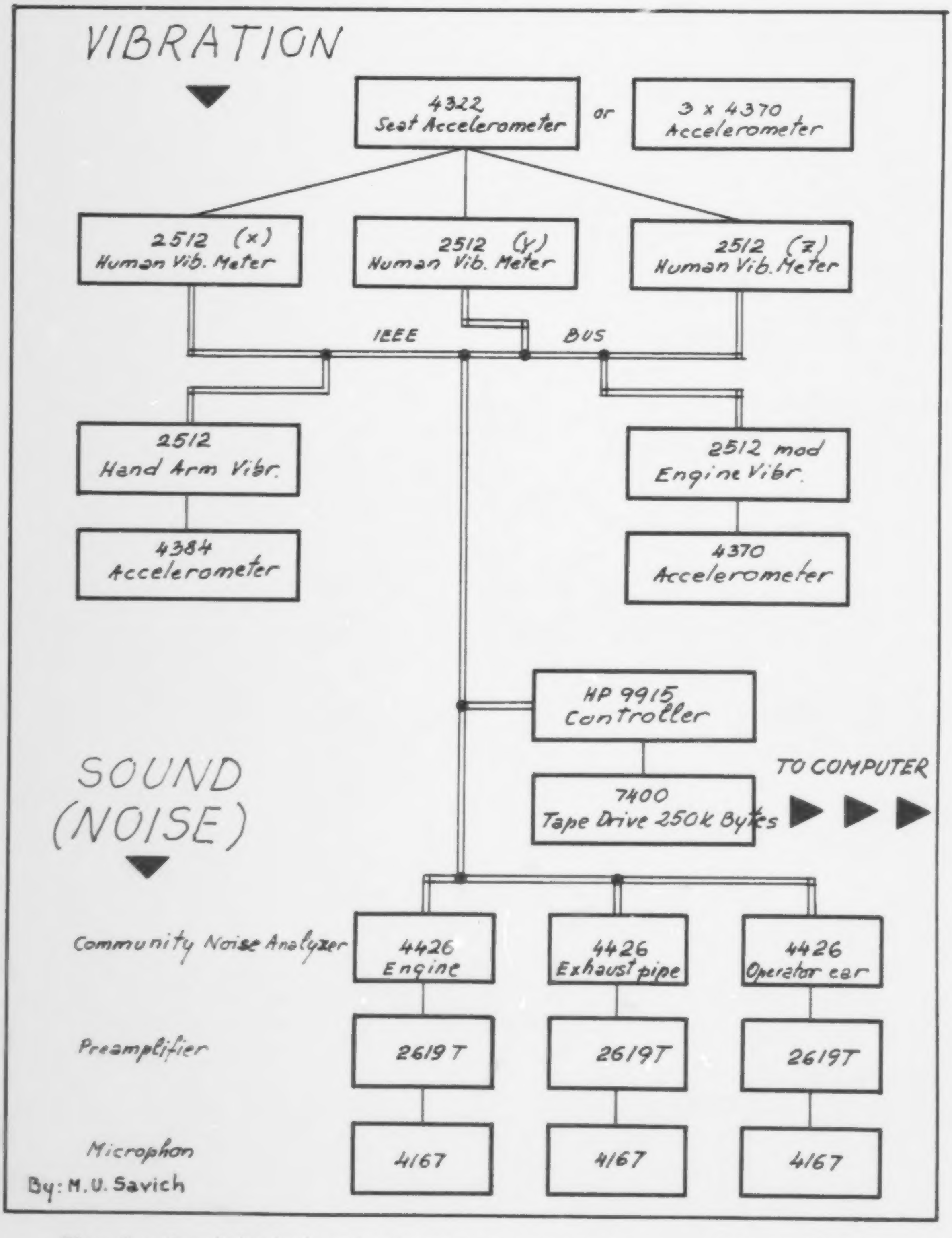
VIBRATION
4322
Seat Accelerometer
or
3 x 4370
Accelerometer
2512 (x)
Human Vib. Meter
2512 (y)
Human Vib. Meter
2512 (z)
Human Vib. Meter
IEEE
BUS
2512
Hand Arm Vibr.
2512 mod
Engine Vibr.
4384
Accelerometer
4370
Accelerometer
HP 9915
Controller
SOUND
(NOISE)
TO COMPUTER
7400
Tape Drive 250k Bytes
Community Noise Analyzer
4426
Engine
4426
Exhaust pipe
4426
Operator ear
Preamplifier
2619 T
2619T
2619T
Microphon
4167
4167
4167
By: M.U. Savich

Fig. 5 - Sound (noise) and vibration measurements on a mining vehicle.

microphones in conjunction with type 2619 preamplifiers. The locations should be on the engine, at the exhaust pipe, and at the operator's ear. Special cabling may be required for this last application. All measurements will be made in dBA, a universally accepted unit.

VIBRATION

The purpose of this equipment is to correlate engine-vehicle vibration with whole body vibration dose to the operator. This dose relates to motion including discomfort and illness.

Whole body information is gathered via a type 4322 Triaxial Seat Accelerometer and is fed to three type 2512 Human Vibration Meters to provide X, Y and Z whole body vibration L_{eg} information. If sensitivity becomes a concern, three type 4370 accelerometers will be used in place of the type 4322. Hand-arm information is gathered by a type 4384 accelerometer and fed to a single type 2512 Human Vibration Meter operating in the hand-arm mode, thus giving Hand Arm L_{eg} information. Both the hand, arm and whole body measurements will be carried-out using ISO compliant equipment.

Engine vibration information will be collected by a single type 4370 and the L_{eg} calculation furnished by a type 2512 specially modified by Bruel and Kjaer to include a flat weighting curve with the appropriate frequency cut off.

CONTROLLER

The system will be controlled by an HP9915 or similar. This controller will pole each of the sound and vibration meters once every 60 seconds, and store the L_{eg} in the type 7400 tape drive. This program will be burnt into PROMs thus eliminating the loading of software and automatic hook-up will be eliminated. Program selection shall be via push-button control with readily accessable RESET,START and PAUSE controls. Provision will be made for the loading of data into a Senturian Series 200 Status Reporting and Control System computer from the type 7400 tape drive.

HOUSING OF EQUIPMENT

The equipment shall be mounted in a NEMA 12 enclosure suitable for placement on a mining vehicle. Elliot Lake Laboratory in cooperation with Bruel and Kjaer will determine the appropriate shape, size and mounting procedure for this item.

INVESTMENT

	Each	Duty Included Total
For sound (noise):		
3 x 4426 Community Noise Analyzer	$8,319.	$24,957.
3 x 2619T Preamplifier	590.	1,770.
3 x A0028 (if required) Extension Cable	447.	1,340.
3 x 4165 Microphone	721.	2,163.
3 x UA0393 Rain Cover (if required)	612.	1,836.
		32,047.
For vibration:		
5 x 2512 Human Vibration Meter	7,739.	38,695.
1 x 4322 Triaxial Seat Accelerometer		2,034.
4 x 4370 Accelerometer (high sensitivity for set)	797.	3,188.
1 x 4384 Hand/Arm Accelerometer		782.
(Also required - accelerometer cable)*		
		44,699.
For sound (noise) and vibration:		
9915 Controller		5,000.*
2 x 7400 Tape drive	7,509.	15,018.
Programming + ROMS		5,000.
10 x A00129 Interfan cables	326.	3,260.
Modification of 2512 for engine vibration		2,000.*
Packaging for underground environment and batteries		5,000.*
		35,278.
Grand Total:		$112,024.

*These items are estimated in firm quotation and will be provided.

CONCLUSION

The major contributors to the high noise level of underground mines by diesel-powered equipment were identified as load-haul-dump machines and ore trucks.

Most difficult problem is to reduce the engine surface noise. The engine noise requires a reduction of more than 10 dBA, to meet OSHA requirement. The noise and vibration are in causal connection.

In general there are three basic ways to reduce combustion noise:

- reduce ignition delay period;
- reduce fuel injected in the ignition delay period; and
- restrict air/fuel mixing during the delay period.

Any changes made to combustion system to reduce noise will affect other aspects of combustion system performance: smoke, fuel consumption and emissions of nitrogen oxides and unburnt hydrocarbons. The research will be very difficult. Total investment in noise and vibration instruments is $122,334.00.

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34. *ISO/DIS* 6394, Acoustics - Measurement of airborne noise emitted by earthmoving machinery - operator's position - stationary test condition.

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Looking ten years backward and ten years forward at the battle against noise and vibration in Canadian mines

1984

DIX ANS DE LUTTE CONTRE LE BRUIT ET LES VIBRATIONS DANS LES MINES CANADIENNES; REGARD SUR LES DIX PROCHAINES ANNÉES

par

M.U. Savich*

RÉSUMÉ

Dans les mines canadiennes, on lutte depuis dix ans contre le bruit et les vibrations. La mesure de l'indice d'exposition au bruit (IEB) et le repérage des principales sources de bruit et de vibrations caractérisent cette période. Les manufacturiers de machines ont entrepris la mise sur le marché d'équipement produisant moins de bruit. En même temps, l'exploitation minière a connu une nouvelle génération d'ouvriers. Au cours des dix prochaines années, on devrait se consacrer à améliorer et à mieux faire connaître les travaux en cours. Pour ce faire, il est impératif de voir à la mise en vigueur immédiate des mesures susmentionnées, de procéder à de sérieuses modifications des machines et de diminuer au maximum le taux de vibrations. Ce programme doit être mené parallèlement à l'accroissement de la productivité.

Les nouveaux instruments de mesure du bruit et des vibrations permettront désormais d'informer pleinement les ouvriers à ce sujet. La constante conscientisation des mineurs au danger représente encore l'une de leurs meilleures défenses.

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LOOKING TEN YEARS BACKWARD AND TEN YEARS FORWARD AT THE BATTLE AGAINST NOISE AND VIBRATION IN CANADIAN MINES

by

M.U. Savich*

ABSTRACT

Ten years of abating noise and vibration in Canadian mines have passed. This period is characterized by measurements of the Noise Exposure Index (NEI) and the pinpointing of main sources of noise and vibration. Machine manufacturers have started marketing equipment that produces less noise. Over the same time a new generation of workers has entered the mining work force. The next ten years should be devoted to improving on and disseminating further the work in progress. To that end are imperative: early enforcement, intensive mending of machines, and the maximum possible decrease in vibration. The entire programme must run in tandem with an increase in productivity.

With the new generation of instruments in noise and vibration, the principle of full information for workers will be materialized. Constantly training miners is important, because their awareness is one of the best defences.

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INTRODUCTION

Over ten years ago intensive work began in Canadian mines on personal protection and audiometric testing. Excessive noise levels in the mining industry were alleged to cause hearing loss in workers. Increasing production required the introduction of large and powerful machinery, the result of which was an increase in noise and vibration. This, in turn, has resulted in the adoption of noise and vibration regulations and standards to create acceptable limits for the worker's exposure.

The guidelines presently in use in Canada are those adopted by the OSHA. Only British Columbia uses Standard ISO R 1999. The International Standard Organization's draft proposal ISO DIS 5399 is currently used for the measurement of hand-transmitted vibration. Whole body measurements have been compared with the standard prescribed by ISO 2631.

Solutions to the noise and vibration problem have come to be concerned with the source, the path and the receiver. Path modification is one of the major methods of protection from noise and vibration. Canadian manufacturers of mining equipment and tools endeavour to reduce the noise and the vibration levels to the minimum possible. Provincial regulations permit the use of personal protective equipment (ear plugs and ear muffs) to meet noise control requirements only if reduction by technical or administrative means is not technically feasible. In recent times, remote control devices have been introduced to mines.

The Canadian mining and metallurgy industry faces a new challenge with the recent technological revolution: the utilization of electronic intelligence functions of machines to increase production and productivity while improving the total environment. Because of this, a new effort has been made to obtain a detailed analysis of ear muffs, in order to improve their application under working conditions, and evaluate the available practical information on the exchange rate to be used in an Ontario noise regulation.

REGULATIONS AND STANDARDS

The guidelines presently used in Canada, excepting British Columbia, are those adopted by the OSHA*, which, for example, permit a worker to be exposed to a noise level of 90 dBA for 8 hours per day and require dividing in half the permissible exposure time for each 5 dBA increase in noise level (Fig. 1). British Columbia has an exchange rate of 3 dB increase for halving of duration (ISO** R1999).

During the last few years there have been several proposals to change OSHA (100% DOSE = 90 dB/8 h), or to convert to the 3 dB exchange rate. In the meantime EPA[†] calculated the cost of adopting a 3 dB exchange rate and the cost of a new OSHA, that would be 85 dB/8 h. Particularly hard hit by the price of implementation would be the mining and metallurgical industries. In EPA's cost analysis some factors were not taken into account: a worker's movements around, and the actual time spent, at a machine; working cycles; and the possibility of using inexpensive protection, or no protection at all. Apart from this, manufacturers have started marketing machines that include devices protecting against noise and vibration. The new technological revolution has brought with it robots and remote control. Many mines have constructed workers' enclosures, or even machine enclosures; and an improved generation of ear muffs and ear plugs is on the market. All these things provide a reason to take a realistic look at the problem.

To better understand the problem, two parallel tables of ISO-OSHA have been constructed (Table 1): Table 1/1 is 100% DOSE = 90 dB/8 h and

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* The Occupational Safety and Health Act (U.S.A.). ** The International Standard Organization. [†] The Environmental Protection Agency.

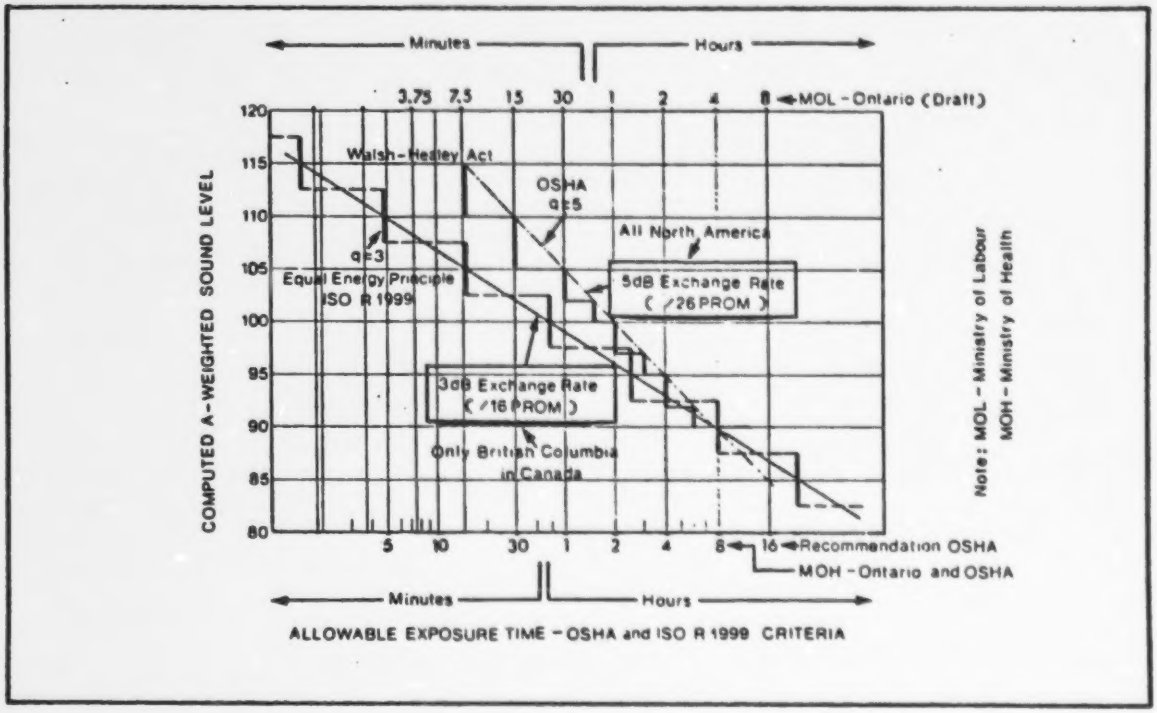

Fig. 1 - The relationship between sound level and duration for the Walsh-Healey Act and ISO R 1999.

Table 1 - Threshold limit values of continuous or intermittent noise under ISO and OSHA

	ISO Noise Dose %	dBA	OSHA Max Time h-min	
8 h	10	80		
	15	82		
	20	83		
	25	84		
	30	85	16-0	Pending
	40	86	13-56	
	50	87	12-8	
	60	88	10-34	
	80	89	9-11	
q = 3	100	90	8-0	
	125	91	6-56	q = 5
	160	92	6-4	
	200	93	5-17	
	250	94	4-36	
	315	95	4-0	
	400	96	3-29	
	500	97	3-2	
	630	98	2-50	
	800	99	2-15	
	1000	100	2-0	
	1250	101	1-44	
	1600	102	1-31	
	2000	103	1-19	
	2500	104	1-9	
	3150	105	1-0	
	4000	106	0-52	
	5000	107	0-46	
	6300	108	0-40	
	8000	109	0-34	
	10000	110	0-30	
	12500	111	0-26	
	16000	112	0-23	
	20000	113	0-20	
	25000	114	0-17	
	31500	115*	0-15	

* No exposure to continuous or intermittent excess of 115 dBA.

Note: Exposure to impulsive or impact noise should not exceed 140 dB peak sound pressure level (OSHA).

(1) 100% Dose = 90 dB/8 h

	ISO Noise Dose %	dBA	OSHA Max Time h-min	
8 h	10	80	16-0	Pending
	15	82	13-56	
	20	83	12-8	
	25	84	10-34	
	30	85	9-11	
	40	86	8-0	
	50	87	6-56	q = 5
	60	88	6-4	
	80	89	5-17	
q = 3	100	▶ 90	4-36	
	125	91	4-0	
	160	92	3-29	
	200	▶ 93	3-2	
	250	94	2-50	
	315	95	2-15	
	400	▶ 96	2-0	
	500	97	1-44	
	630	98	1-31	
	800	▶ 99	1-19	
	1000	100	1-9	
	1250	101	1-0	
	1600	▶ 102	0-52	
	2000	103	0-46	
	2500	104	0-40	
	3150	▶ 105	0-34	
	4000	106	0-30	
	5000	107	0-26	
	6300	▶ 108	0-23	
	8000	109	0-20	
	10000	110	0-17	
	12500	▶ 111	0-15	
	16000	112		
	20000	113		
	25000	▶ 114		
	31500	115*		

* No exposure to continuous or intermittent excess of 115 dBA.

Note: Exposure to impulsive or impact noise should not exceed 140 dB peak sound pressure level (OSHA).

(2) 100% Dose = 85 dB/8 h

Table 1/2 is 100% DOSE = 85 dB/8 h. Table 1/1 shows that the present regulations give better results over the full scale. Table 1/2 shows that ISO produces lower results up to 100 dBA. From Table 2 it is clear that only on two occasions does L_{OSHA} go over the 100 dBA level: Jumbo operator (103.78 dBA) and Stope instructor/training (100.5 dBA). In no case was the noise of machines equal to L_{OSHA}, L_{OSHA} always being lower than the sound pressure level. Measurements were taken in the crushing and screening plant with a threshold (CUT OFF) level of 85 dB. During other measurements the threshold (CUT OFF) level was 80 dB. The resultant doses are higher than normal, which is to the advantage of the employees. This example makes an overwhelming case for accepting the 3 dBA exchange rate.

As far as measuring impact noise is concerned, the instruments exist, but counting impulses and their lengths during a shift creates complications, because of the instruments' performance. The solution to this problem lies with instrument manufacturers and science institutions involved with acoustics.

HEARING PROTECTION

The aim of this paper is to show of how much assistance are ear muffs and plugs in working conditions. None of the results are evaluated according to standards, but give a realistic picture. From Table 3, one can see that the attenutation is around 15 dBA, and that is in the best circumstance.

As far as ear plugs are concerned, the best results are obtained with foam plugs, with an attenuation of 11 dB under working conditions (1). The combination of ear muffs and plugs raises the attenuation to 23 dBA. Using the new ear muffs and plugs presently on the market, it is imperative to again perform measurements, employing a uniform procedure, in the mines. When purchasing ear muffs, practical attenuation results should be taken into

Table 2 - Results of L_{OSHA} and time during work day in local mines.

The Crushing and Screening Plant

No.	Operation	No. of Samples	Working time (min)	Shift (dBA/min)				L_{OSHA} (dBA)
				60-79	80-115	85-115	90-115	
1	Crusher operator	9	426	242	238	221	194	92.93
2	Mechanic	12	446	326	154	133	98	85.64
3	Welder	5	451	338	141	110	721	83.11
4	Electrician	1	447	398	82	55	35	80.00
5	Shift boss	1	424	294	183	154	125	88.90
6	Foreman	2	468	455	25	16	8	70.91
		10						Log Ave

Drilling Operations

No.	Operation	No. of Samples	Working time (min)	Shift (dBA/min)				L_{OSHA} (dBA)
				60-79	80-115	85-115	90-115	
1	Jumbo operator	19	477	157	323	288	241	103.78
2	Roof bolter	19	478	183	297	261	218	99.35
3	Miner	41	480	271	209	160	126	99.63
4	Longhole driller	1	480	95	385	371	358	99.30
5	Diamond driller	4	480	169	311	283	186	97.37
6	Giraffe operator	5	480	146	334	305	258	97.32
7	Stop Instr/train	6	480	177	303	268	216	100.15
8	Shift boss	9	480	315	165	133	85	86.12
9	Foreman	2	480	296	184	147	111	87.09
		106						Log Ave

Haulage Equipment

No.	Operation	No. of Samples	Working time (min)	Shift (dBA/min)				L_{OSHA} (dBA)
				60-79	80-115	85-115	90-115	
1	Scooptram oper.	14	479	135	344	317	274	97.89
2	Dux truck oper.	5	480	209	271	225	173	90.35
3	J.D.T. operator	6	480	135	345	318	268	97.42
4	Utility vehicle	3	480	277	203	171	135	92.52
5	Truck driver	5	480	129	351	326	284	97.89
6	Equip. operator	3	480	137	343	320	301	96.22
		36						Log Ave

Table 3 - Field performance of ear muffs

Source	No. of Ear Muffs	Attenuation (dBA)	
		Average*	Mean
E.H. Berger (1)	8	12.26	11.38 ± 3.02
M. Savich† (2)	8	13.99	12.64 ± 3.45
M. Savich†† (3)	9	17.82	14.79 ± 5.68
Σ	25	15.33	13.01 ± 4.36

NOTE: * $\overline{SPL} = 10 \log \frac{1}{n} [\text{antilog} \frac{SPL_1}{10} + \text{antilog} \frac{SPL_2}{10} + \text{---} \text{antilog} \frac{SPL_n}{10}]$

† The same muffs used in mines.

†† Different and brand new.

account, because the greatest noise reduction is not always given by ear muffs which have the best attenuation characteristics in the laboratory. A new standard is necessary, for tests to be uniform under working conditions. This standard would be the impetus to manufacturers to improve their products, and to consumers to develop better judgement in selecting their equipment.

CONCLUSIONS

The Canadian mining industry has taken measures in an effort to protect the environment, create satisfactory conditions, compensate and create a positive environment for advancement in providing solutions to our most pressing problems: providing Canadian mines and mills with advanced technology to help Canada become effective, economical and environmentally acceptable, and more competitive in world markets.

With new generation instruments in noise and vibration, the principle of full information for workers will be materialized. Management will have great use for this, since they will be able to follow-up on maintenance, work efficiency and protection. Also, the closer union between workers and management has important and beneficial economic and social repercussions.

There are many reasons to make a new effort in adopting an exchange rate of 3 dB and a 100% DOSE = 90 dBA/8 h. Employing the new instruments, we must assist in maintenance, and in following consistent increases or decreases of machine noise and vibration.

Man does not live for production and the environment alone. Life offers too much for that to be. Zero risk does not exist, and trying to attain it would be in vain. Man's only duty is to do the best possible. Workers in mines must be given lessons on how to combat noise and vibration. Awareness is one of the best defences.

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Heliport at Sudbury Hospital

1983

HELIPORT AT SUDBURY GENERAL HOSPITAL

by

M.U. Savich* and B.S. Harris**

ABSTRACT

This report is an open discussion on the proposed heliport at the Sudbury General Hospital, its potential as a noise hazard and possible solutions.

The study indicates that use of an acoustical barrier is not an efficient method of noise attenuation at the hospital. Our recommendation is that the glass in the windows of the rooms affected should be changed to acoustical glass on 'double windows'. This would provide an effective form of noise attenuation. Thus, the implementation of a heliport at the Sudbury General Hospital is feasible.

The results of this study show the potential for assisting not only the Sudbury General Hospital, but the Northern Ontario community at large.

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RAPPORT SUR L'HÉLIPORT DE L'HÔPITAL GÉNÉRAL DE SUDBURY

par

M.U. Savich* et B.S. Harris**

RÉSUMÉ

Ce rapport constitue une discussion générale au sujet du futur héliport de l'Hôpital général de Sudbury, des risques de bruits élevés et des solutions possibles à ce problème.

L'étude effectuée démontre que l'utilisation d'un écran acoustique ne représente pas une méthode efficace pour réduire le bruit à l'hôpital. Nous recommandons de changer le verre des vitres par du verre acoustique posé sur les châssis doubles des fenêtres concernées. Ceci devrait servir de moyen efficace pour diminuer le bruit. De cette façon, il sera possible de construire l'héliport à l'Hôpital général de Sudbury.

Les résultats de cette étude demontre la possibilité de venir en aide non seulement à l'Hôpital général de Sudbury, mais aussi à toute la communauté du nord de l'Ontario.

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INTRODUCTION

Noise measurement in the Sudbury General Hospital is directed towards the following objectives:

1. To identify noise in the A-weighted network of the helicopter in the Intensive Care Units Room, X-Ray Special Procedures Room and Technical Director's Office.
2. To obtain representative full octave band measurements and analyses of noise in Intensive Care Units Room, X-Ray Special Procedures Room and Technical Director's Office.
3. To give solutions for sound level attenuation in Intensive Care Units Room, X-Ray Special Procedures Room and Technical Director's Office, if necessary.

The scope of this report is to open discussion on the proposed heliport at the Sudbury General Hospital, its potential as a noise hazard and possible solutions.

The results of this study show the potential for assisting not only the Sudbury General Hospital, but the Northern Ontario community at large.

INSTRUMENTS

All measurements were taken using the Brüel and Kjaer Precision Integrating Sound Level Meter Type 1613, Level Recorder Type 2306, Sound Level Meter Type 2205, and Integrating Vibration Meter Type 1513. The sound level meter and integrating sound level meter were used to observe the sound levels. Both instruments were operated on the A-weighted network and calibrated with the calibrator before and after measurements. Time history sound level measurements were taken with the sound level meter and a portable level recorder. The level recorder gave a graphical display of the sound level as a function of time (Appendix A). For frequency analysis an external filter was connected to the precision integrating sound level meter. Records of such surveys show data and location of the test. Vibration records in acceleration and velocity modes were taken only in X-Ray Special Procedures Room.

MEASUREMENTS OF NOISE AND VIBRATION IN THE HOSPITAL PRODUCED BY THE HELICOPTER

During the time period when the helicopter was hovering over the proposed landing site, measurements were taken in the hospital in (Fig. 1):

- The Intensive Care Units Room
- X-Ray Special Procedures Room, and
- Technical Director's Office.

Measurements were taken by the window in a five-bed area of the Intensive Care Unit (Fig. 2). Staff on duty reported that there was no apparent effect on the equipment in operation in the I.C.U. at that time. The staff noted a significant amount of vibration of the windows by 'bed 7', and to a lesser degree of the window where the test was taken. Table 1 shows the results of all measurements taken at the hospital.

Table 1 - Noise in hospital during experiment with the helicopter

Location	dBA				Remarks
	Background Noise	Low	High	Open Window	
Intensive Care Units Room	63	64.5	82.5	-	Full of patients
X-Ray Special Procedures Room	56	57.5	58	-	Instrumentations increased noise
Technical Director's Office	58	65	67	84 to 90	Open door

In the X-Ray Special Procedures Room there was no increase in noise. The main concern was that the helicopter outside a room could cause the walls

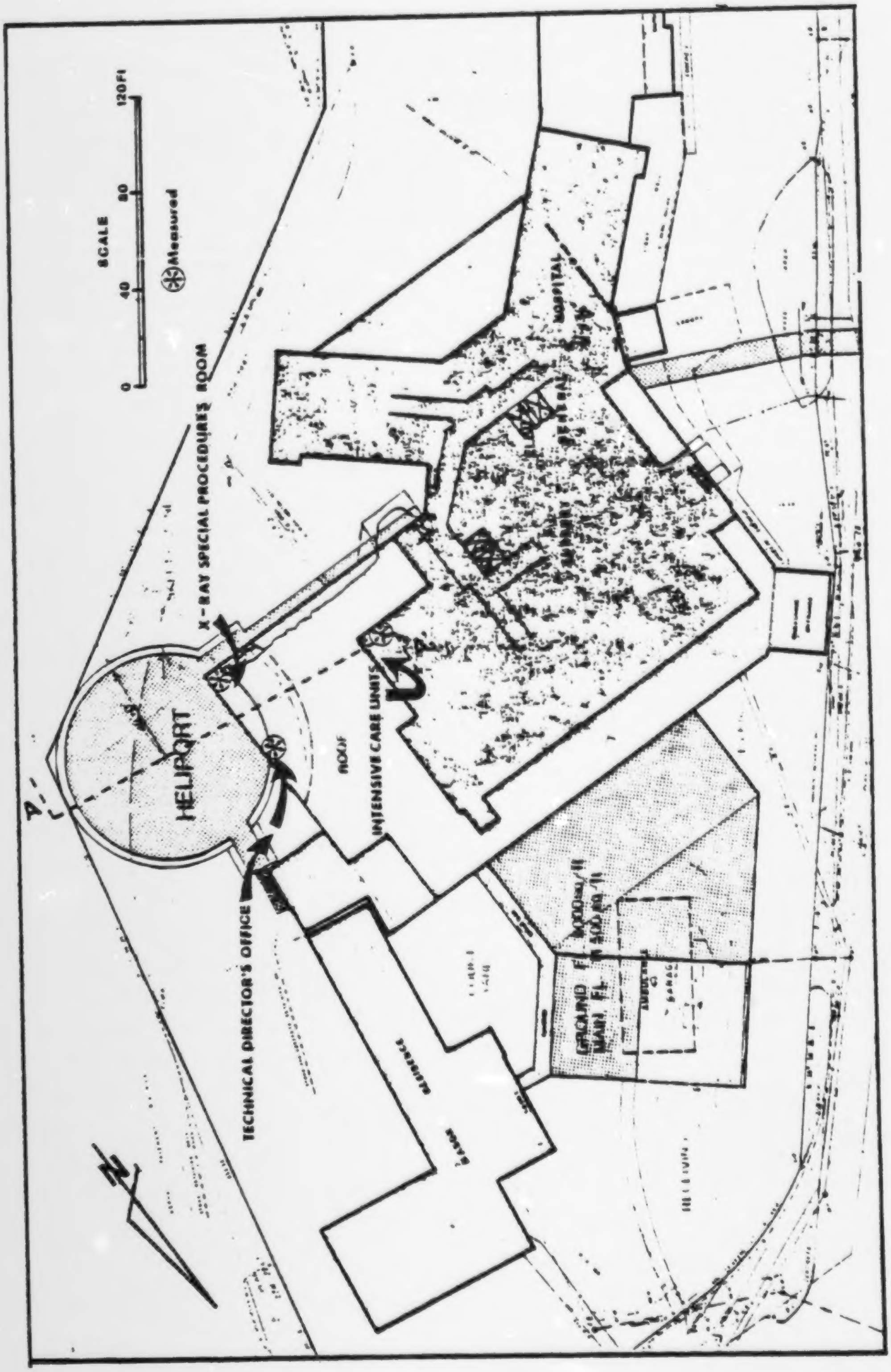

SCALE
0
40
80
120FT
Measured
X-RAY SPECIAL PROCEDURES ROOM
HELIPORT
TECHNICAL DIRECTOR'S OFFICE
ROOF
INTENSIVE CARE UNITS
SUDBURY GENERAL HOSPITAL
GROUND FL
MAIN FL
N

Fig. 1 - Heliport at Sudbury General Hospital.

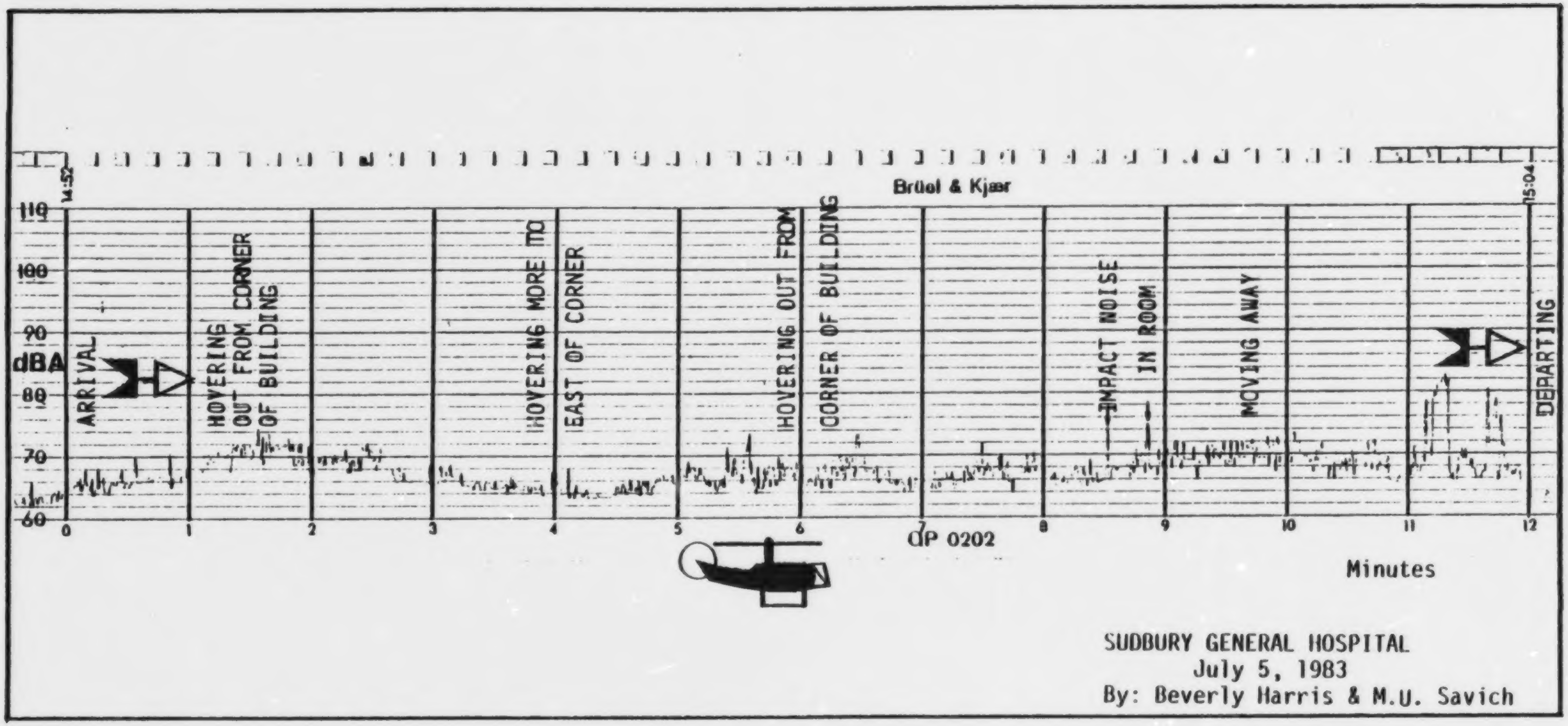


Fig. 2 - Time history graph in the Intensive Care Unit at the Sudbury General Hospital during the experiment.

to vibrate and thus produce noise in a room. In addition, floor vibration could cause problems if delicate operations were being performed, or if sensitive instruments were present nearby. All vibration measurements are very low. They did not show any readings on vibration meter type 2513. In the Technical Director's office noise was around 66 dBA: with the window open the levels were between 84 and 90 dBA. All measurements taken inside the hospital indicate that noise is not a significant factor. Rather, the psychological effect may be more important.

NOISE CRITERIA CURVES

The octave-band noise spectrum in rooms at Sudbury General Hospital was measured (Fig. 3) in:

- Intensive Care Units (only one patient)
- X-Ray Special Procedures Room (room was empty), and
- Technical Director's Office (room was empty).

Total noise estimated in dBA from the octave-band noise levels given in the first eight columns are in approximate agreement with the total noise measured which indicated reasonably constant conditions during the period of measurement.

A method of rating the background noise level in a room is accomplished through use of Noise Criteria (NC) curves (Fig. 4). These curves were established in 1957 for rating indoor noise (1,2). Each curve specifies the maximum octave-band sound pressure level for a given NC rating. As the area of noise control progressed over the years, the NC curves led to their modification (2). The new curves are called the Preferred Noise Criteria (PNC) curves (Fig. 5). Although these curves differ from the NC curves, they are used in the same manner.

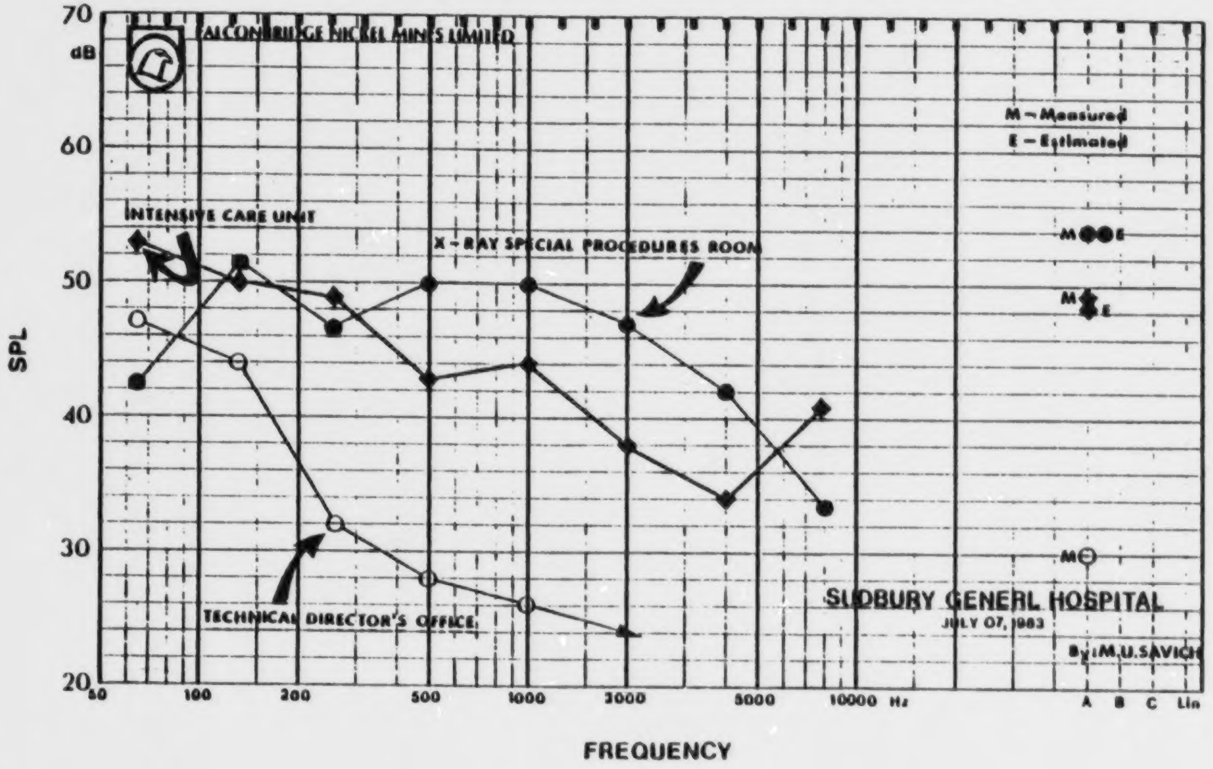


Fig. 3 - Frequency spectrum of noise in rooms at Sudbury General Hospital.

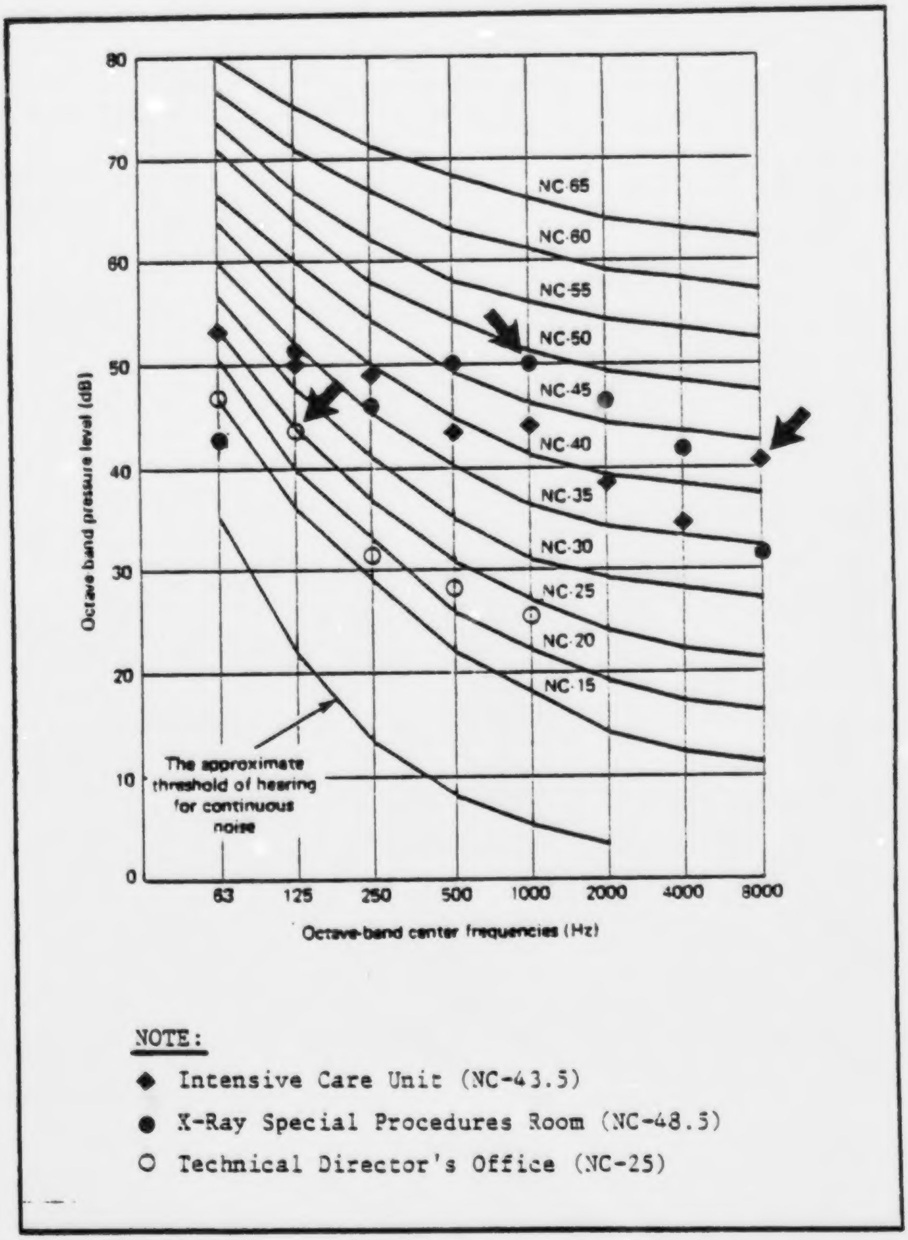
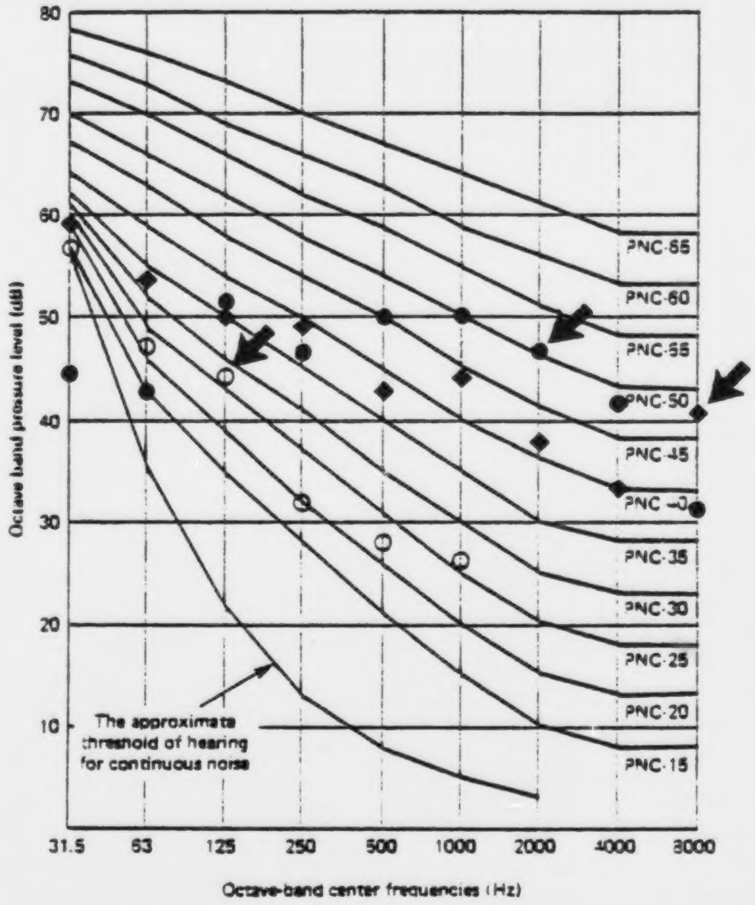


Fig. 4 - The Noise Criteria (NC) curves were plotted using the data from the frequency spectrum in rooms.



NOTE:

- ◆ Intensive Care Unit (PNC-44)
- ● X-Ray Special Procedures Room (PNC-50.5)
- ○ Technical Director's Office (PNC-27).

Fig. 5 - The Preferred Noise Criteria (PNC) curves were plotted using the data from the band pressure levels.

Recommended noise criteria ranges for steady background noise in certain indoor areas are listed in Table 2 (3):

Table 2 - Ranges of Noise Criteria (NC) and Preferred Noise Criteria (PNC) curves

Location	NC Curve	PNC Curve
1. Sleeping quarters	25 - 35	25 - 40
2. Living quarters	35 - 45	30 - 40
3. Office or classroom	30 - 35	30 - 40
4. Recording studio	12 - 20	10 - 20
5. Retail store or restaurant	35 - 50	35 - 45
6. Laboratory or engineering	40 - 45	40 - 50
7. Computer areas	45 - 60	45 - 55

From the octave-band noise spectrum in rooms in Fig. 4 and 5, and Table 2 the following was found:

	NC Curve	PNC Curve
- Intensive Care Unit (= Laboratory or Engineering)	40 - 45	40 - 50
- X-Ray Special Procedures Room (= Computer areas)	45 - 60	45 - 55
- Technical Director's Office (= Sleeping quarters)	25 - 35	25 - 40

This is usually a satisfactory solution of the hospital's permissible level.

ACOUSTIC BARRIER

The acoustic barrier provides a possible means to reduce the sound pressure level due to the direct field of the source at a given position. The distances between the barrier, the source, and the receiver are very important.

BARRIER - INSERTION - LOSS FORMULATION AND APPROXIMATION FOR BARRIERS

A simplified expression may be derived for the semi-infinite barrier in free-field environment for Sudbury General Hospital (Fig. 6).

For this case, the general expression for the insertion loss (4) as given by Equation 1 is:

$$IL = -10 \text{ Log } \left(\frac{\lambda}{3\lambda + 20\delta_1}\right) \text{ dB} \qquad \text{Eq 1}$$

where, λ = wave length (m or ft)

δ_1 = difference in direct path and diffracted path between the source and receiver (m or ft), and as designated in Fig. 1 is:

$$\delta_1 = [(R^2 + H^2)^{\frac{1}{2}} + (D^2 + H^2)^{\frac{1}{2}} - (R + D)] \text{ m or ft}$$

$$\delta_1 = \{R[1 + \frac{H^2}{R^2} - 1] + D[(1 + \frac{H^2}{D^2})^{\frac{1}{2}} - 1]\} \text{ m or ft} \qquad \text{Eq 2}$$

We shall assume that (Fig. 1) $D >> R \geq H$

which allows to reduce δ_1 to $\delta_1 = R[(1 + \frac{H^2}{R^2})^{\frac{1}{2}} - 1]$ m or ft Eq 3

Applying the binomial theorem and keeping only the first two terms, one obtains:

$$(1 + \frac{H^2}{R^2})^{\frac{1}{2}} \approx (1 + \frac{H^2}{2R^2})$$

which is substituted into Equation 3 to obtain:

$$\delta_1 \approx \frac{H^2}{2R} \text{ m or ft} \qquad \text{Eq 4}$$

We substitute Equation 4 into Equation 1 to obtain:

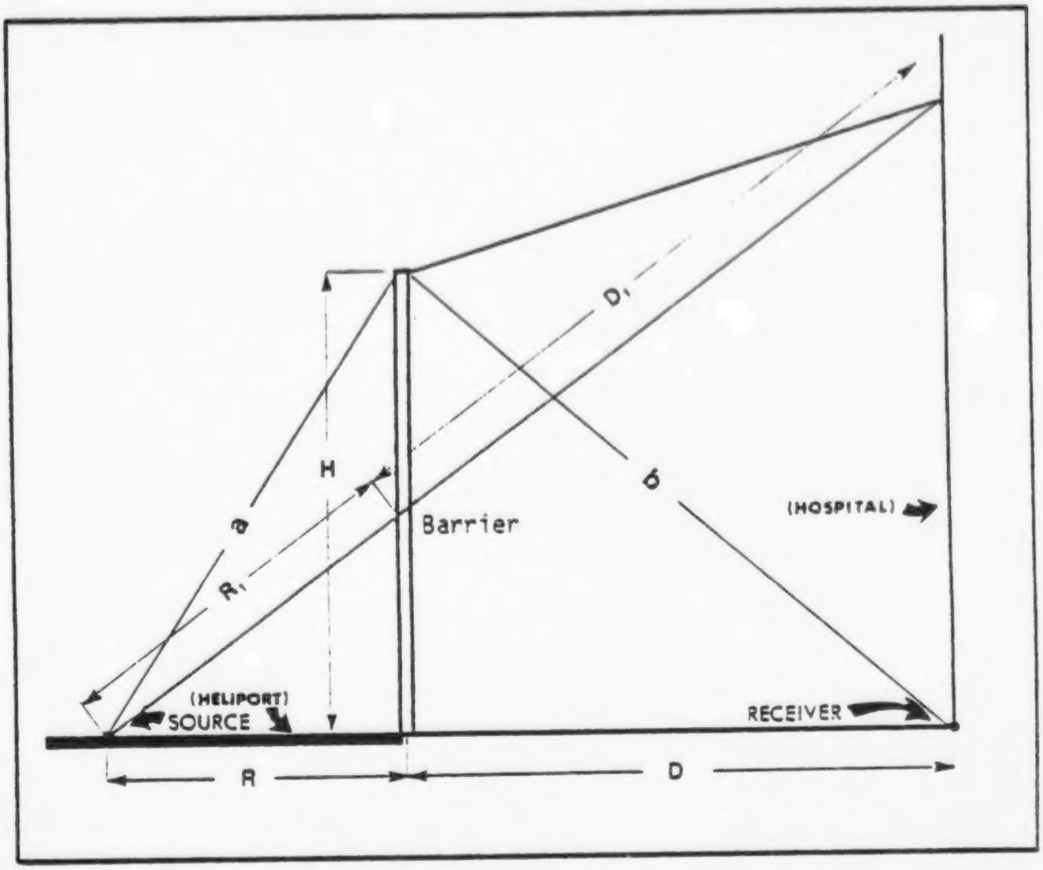
$$IL \approx 10 \text{ Log } \left[\frac{\lambda}{3\lambda + (10H^2/R)}\right] \text{ dB} \qquad \text{Eq 5}$$

and from theory assuming that:

$$3\lambda << \frac{10H^2}{R}$$

one finally obtains:

$$IL \approx 10 \text{ Log } \left(\frac{10H^2}{\lambda R}\right) \text{ dB} \qquad \text{Eq 6}$$



H
D_1
a
b
R_1
Barrier
(HOSPITAL)
(HELIPORT)
SOURCE
RECEIVER
R
D

Fig. 6 - A semi-infinite barrier (general).

In Fig. 7 we see that a barrier would be ineffective as a method of noise abatement since the major portion of noise from the helicopter is during take-off and landing. The helicopter engine is not running during patient transfer to and from the helicopter (per discussion with pilot).

SOUND TRANSMISSION THROUGH WINDOWS

The existing windows found at the Sudbury General Hospital provide an attenuation factor of approximately 23-25 dB. Since the noise from the helicopter is not too high, this is satisfactory. Sound transmission through windows varies with the frequency of the sound and the weight (or mass). The Transmission Loss (TL) at 'double windows' performs better than the mass law predicts.

In order to better understand this problem, information is provided regarding the Sound Transmission Class of window and glazing.

The Sound Transmission Class (STC) is a single-number classification used to rate the transmission loss of a wall. The higher the STC value, the more efficient the wall is in reducing sound transmission.

Table 3 - Determination of Sound Transmission Class (5).

STC - ratings of windows and glazing.

	Construction	Thickness	Weight (lb/ft^2)	STC Rating
Poor	D.S. glass	1/8" (3 mm)	1 - 1/2	21
	1/4" plate glass	1/4" (6 mm)	3	26
	1" insulating glass	1" (2.5 cm)	6 - 1/2	32
Good	9/32" laminated acoustical glass*	9/32"	3 - 1/4	36
	Glass block	3 - 3/4"	20	40
Excellent	Spaced glass (1/4" - 2" air space - 1/4"	2 - 1/2"	6 - 1/2	42

* "Acousta - pane 36"

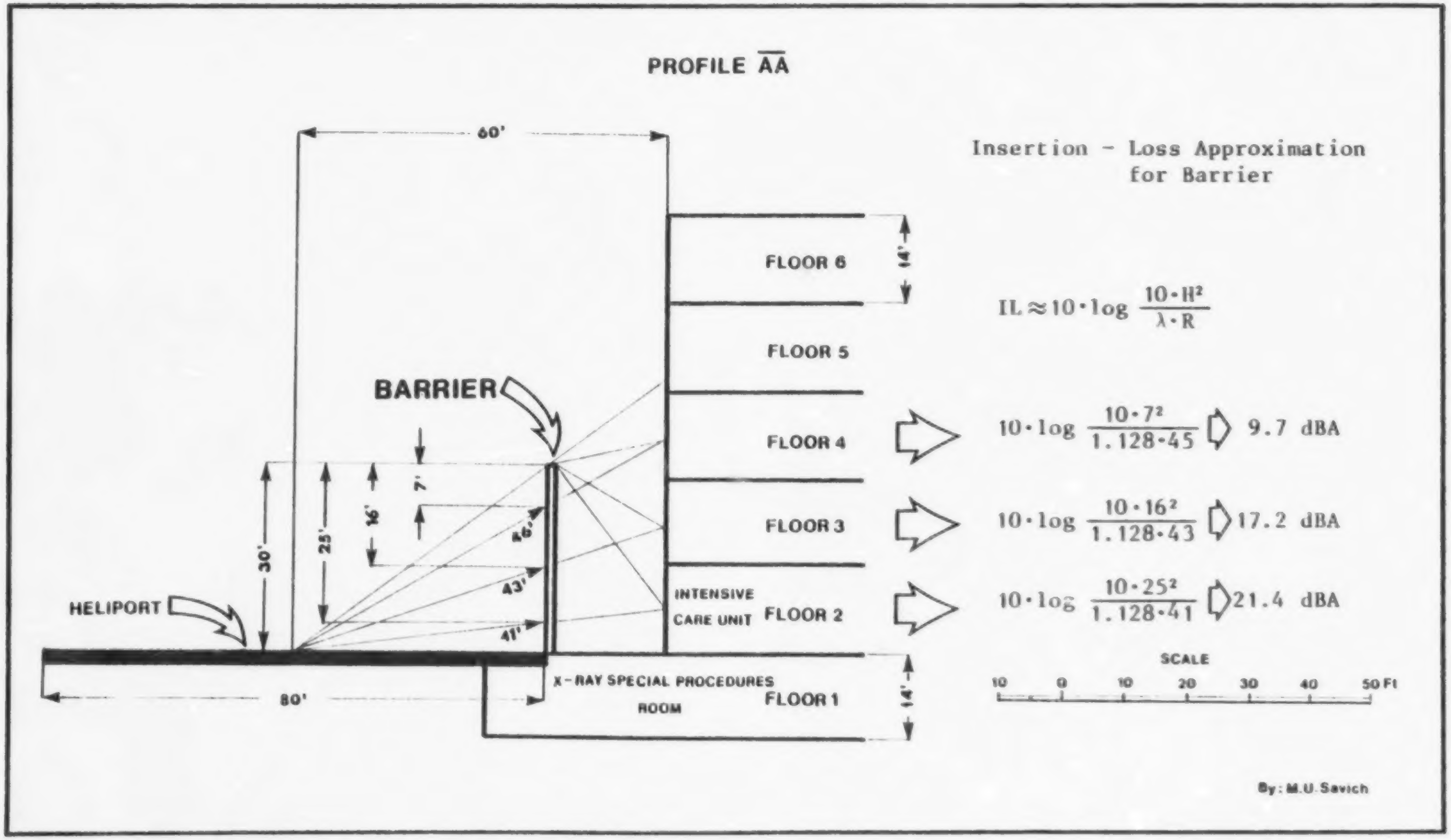

PROFILE $\overline{AA}$
60'
BARRIER
HELIPORT
30'
25'
16'
7'
46'
43'
41'
80'
FLOOR 6
FLOOR 5
FLOOR 4
FLOOR 3
INTENSIVE CARE UNIT FLOOR 2
X-RAY SPECIAL PROCEDURES ROOM
FLOOR 1
14'
14'
Insertion - Loss Approximation for Barrier
$IL \approx 10 \cdot \log \frac{10 \cdot H^2}{\lambda \cdot R}$
$10 \cdot \log \frac{10 \cdot 7^2}{1.128 \cdot 45}$ 9.7 dBA
$10 \cdot \log \frac{10 \cdot 16^2}{1.128 \cdot 43}$ 17.2 dBA
$10 \cdot \log \frac{10 \cdot 25^2}{1.128 \cdot 41}$ 21.4 dBA
SCALE
10
0
10
20
30
40
50 Ft
By: M.U. Savich

Fig. 7 - Insertion - loss approximation for barrier at Sudbury General Hospital.

Sound transmission through windows varies with the frequency of the sound and the weight (or mass).

HELICOPTER AS A SOURCE OF NOISE

At Sudbury Air Ambulance Base, noise measurements were taken on the Helicopter Bell 212, the same as used in the experiment at the Sudbury General Hospital (Fig. 8). Measurement of all frequencies show that in hover status it is predominately low frequency noise with the maximum noise level being 107 dBA. In idle status, noise level is approximately 90 dBA.

Table 4 shows the noise measurements taken at four points from a distance of 40 ft from the helicopter (projected heliport is 80 ft diameter). Measurements were taken with two instruments at the same time and point, and then averaged in dBA network. Two measurements at the right and rear were not taken since the helicopter was called out for an emergency.

Table 4 - Noise from helicopter at a distance of 40 feet

Status	dBA							
	Front		Left		Right		Rear	
	1+	2*	1	2	1	2	1	2
Idle	94	90	91	90	94	91	92	90
	92		90.5		92.5		91	
Hover (8 ft.)	106	106	107	102	-	-	-	-
	106		104.5		-		-	

Note: 1+ - Level Recorder Type 1306 without windscreen.
2* - Precision Integrating Sound Level Meter Type 1613 with windscreen.

Noise levels were also taken inside the helicopter in order to investigate the level of noise which a patient would be exposed to in the transport (Table 5).

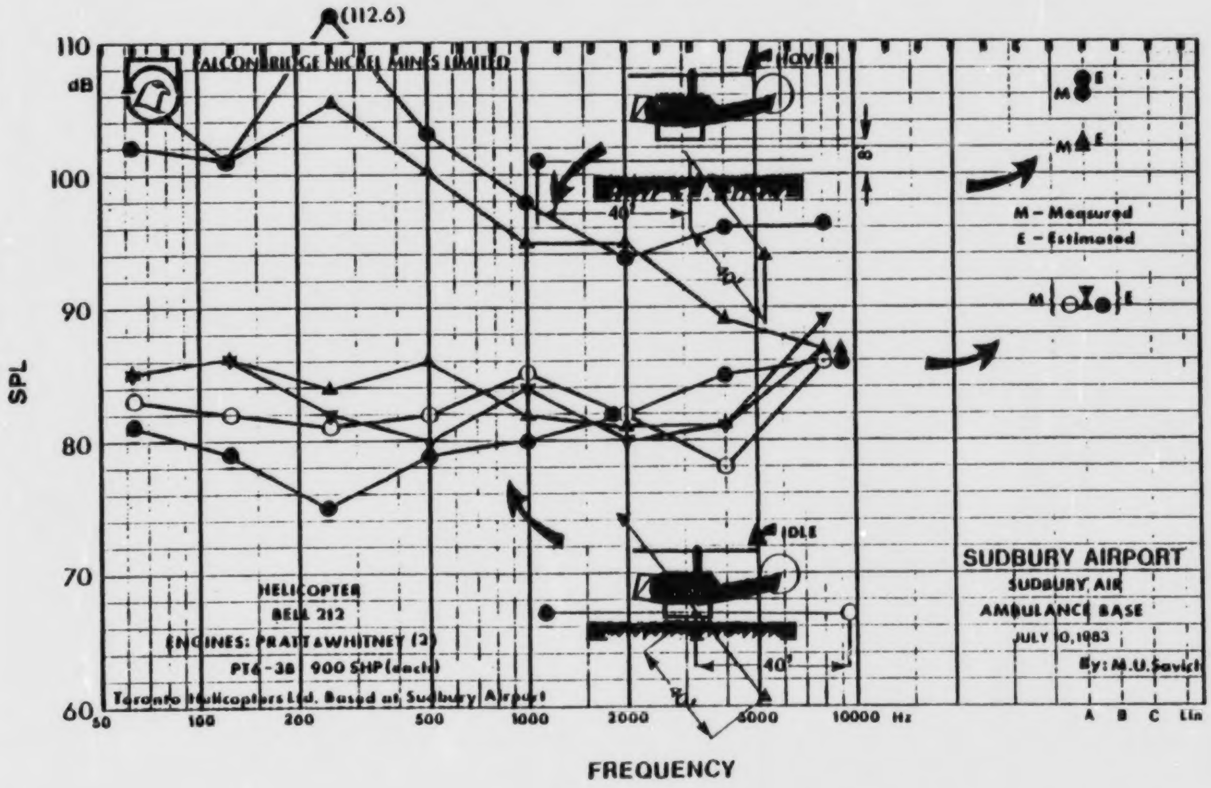


Fig. 8 - Frequency spectrum of noise at the helicopter Bell 212 at Sudbury General Hospital.

Table 5 - Noise inside helicopter

Status	dBA			
	Front		Back	
	Co-Pilot	Pilot	Left	Right
On ground, full rpm	94(?)	86	88	88
Hover 8 ft.	86	87	88	86
In flight	92	92	87	85

Note: Measured with Level Recorder Type 2306 from the pilot.

In general, one may conclude that the noise levels from the helicopter are not high enough to cause concern.

CONCLUSION

Noise measurements were taken at the Sudbury General Hospital, (Intensive Care Unit, X-Ray Special Procedures Room and Technical Director's Office), and of the helicopter at the Sudbury Air Ambulance Base.

This study indicates that use of an acoustical barrier is not an efficient method of noise attenuation at the hospital.

Our recommendation is that the glass in the windows of the rooms affected should be changed to acoustical glass or 'double windows'. This would provide an effective form of noise attenuation. Thus, the implementation of a heliport at the Sudbury General Hospital is feasible.

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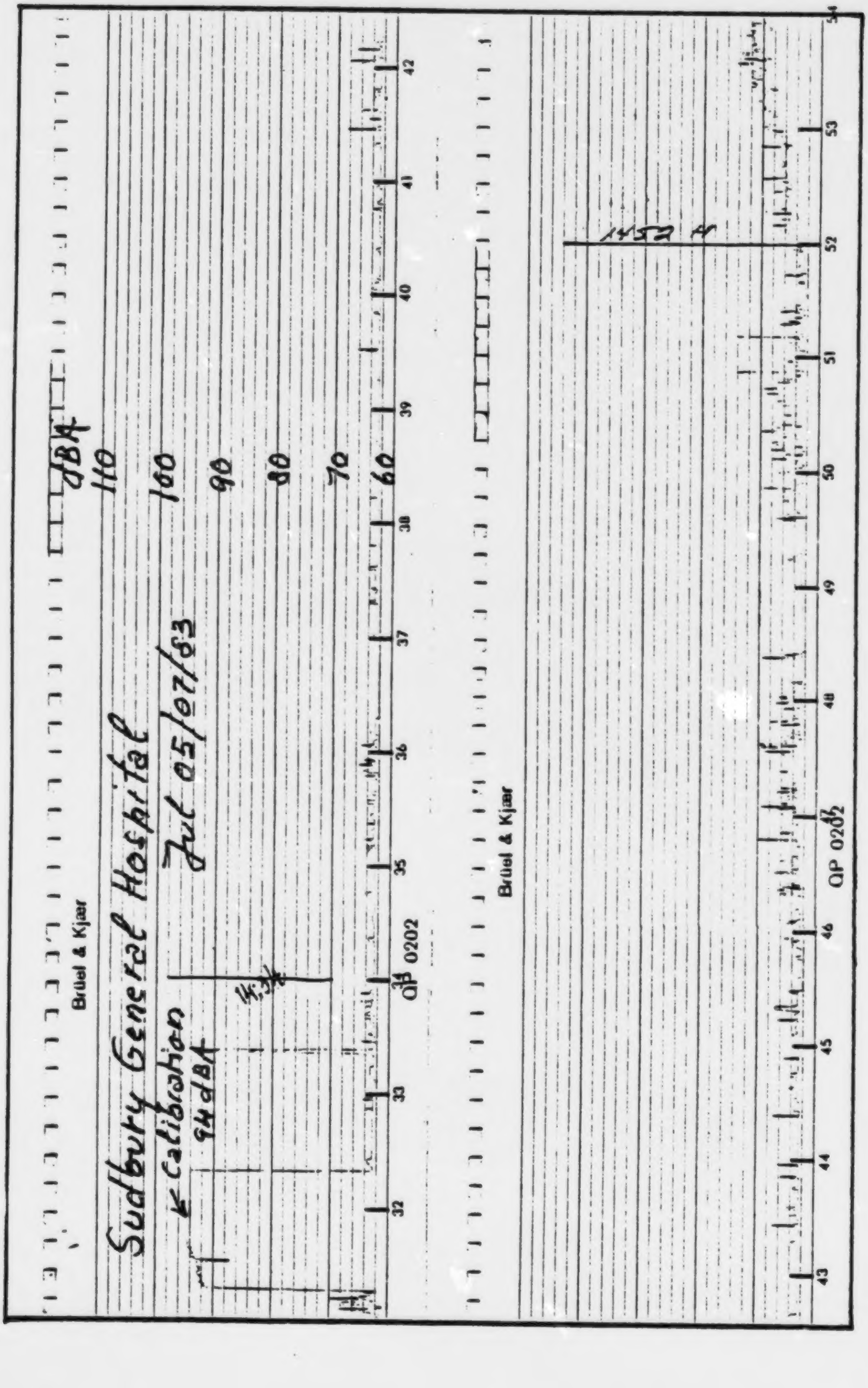
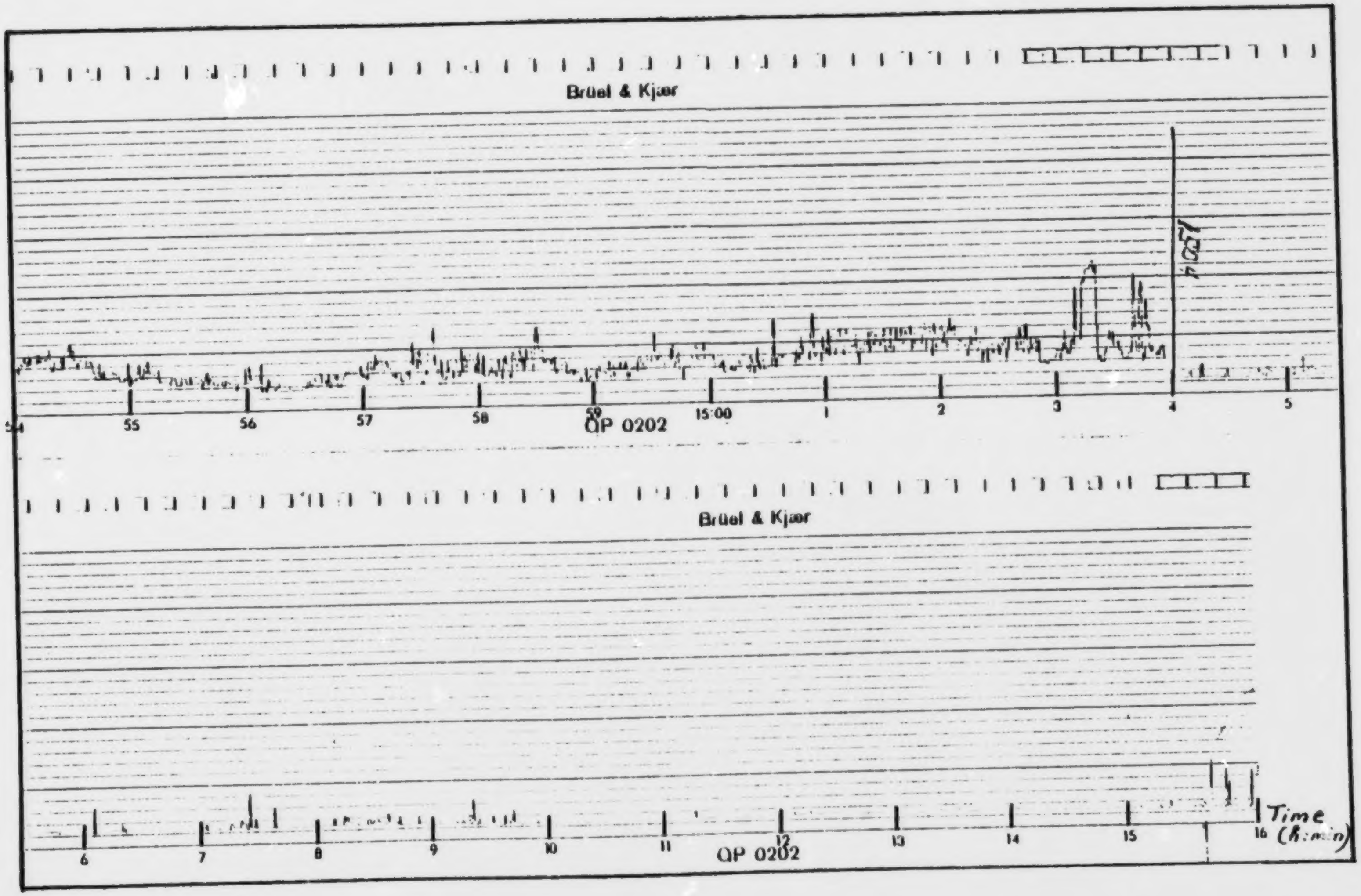


Appendix A - Time history graph from 14.34 h to 15.16 h, July 5th, 1983.



Appendix A - Continued.